Appendix – Chapter 2.1

Water Quality Data

Technical Memorandum

Final

PondWatch Nutrient Related Water Quality
Bournes Pond, Great Pond, Green Pond,
Little Pond, Oyster Pond, West Falmouth Harbor:

SMAST POST-MEP Sampling Assessment (2004-2017)

To:

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Falmouth PondWatch

Introduction: The Coastal Systems Program (CSP) at the University of Massachusetts-Dartmouth (UMD) School for Marine Science and Technology (SMAST) is currently undertaking a detailed assessment of nutrient cycling in the bottom sediments of Bournes Pond, specifically related to the interaction between water quality and shellfish propagation of oysters in floating bags. The Bournes Pond sediment-water column nutrient assessment is being completed in the context of a synthesis of historic (post-MEP) nutrient related water quality in Bournes Pond as well. For the purpose of this assessment, the historic (pre-MEP baseline) data was related to post-MEP water quality data from 2004-2016 and data collected through the PondWatch Monitoring Program in the summer of 2017. The synthesis of the Bournes Pond nutrient related water quality data was also compared to parallel data from other Falmouth estuaries (particularly Green Pond and Great Pond) that have not had significant alteration of nitrogen inputs or outputs and that are currently monitored by the Falmouth PondWatch Water Quality Monitoring Program. Water quality characteristics from similarly structured nearby estuarine systems serve as external control for evaluating Bournes Pond water quality both before and after any large scale oyster deployment. The inter-estuarine comparison will provide the Town of Falmouth with a clear picture of the range of water quality conditions in Bournes Pond and the other 5 PondWatch estuaries, how Bournes Pond water quality compares to the other systems, and the scale of natural annual variation in these estuaries. The water quality information can also inform the Town as to which areas may be suitable for shellfish seeding and how the seeding of oysters in other Falmouth estuaries might affect nutrient cycling.

Background: Coastal salt ponds and estuaries are among the most productive components of the coastal ocean. These circulation-restricted embayments support extensive and diverse plant and animal communities providing the foundation for many important commercial and recreational fisheries. The aesthetic value of these systems, as well as the freshwater ponds of a town, are important resources to both residents and the tourist industry alike. Maintaining high levels of water quality and ecological health in these aquatic systems (fresh and marine) is fundamental to the enjoyment and utilization of these valuable resources for all coastal communities.

Nutrient over-enrichment is the major ecological threat to water quality in the salt ponds and estuaries within the Town of Falmouth, ultimately resulting in ecological degradation when nutrient loading exceeds the assimilative capacity (also called critical nutrient threshold) for new inputs. Of the various forms of pollution that threaten coastal waters (nutrients, pathogens and toxics), nutrient inputs are the most ubiquitous, insidious and difficult to control. This is especially true for nutrients originating from non-point sources, such as nitrogen and phosphorous transported in the groundwater from on-site septic treatment systems. On-site Title 5 septic treatment systems continue to be the primary mechanism for waste disposal within Falmouth's coastal watersheds.

As a result of nutrient loading to Falmouth's coastal watersheds, many of the 14 estuaries within the Town have been supporting signs of nutrient impaired water quality and resource loss for more than a decade. As a result, the University of Massachusetts-Dartmouth, specifically scientists from the Coastal Systems Program (School for Marine Science and Technology) has been conducting a unified and comprehensive water quality monitoring program (Falmouth

PondWatch) in six estuaries of the Town (West Falmouth Harbor, Oyster Pond, Little Pond, Great Pond, Green Pond and Bournes Pond) since the 1990's. These data established the nitrogen related water quality baseline (pre-MEP) employed by the Massachusetts Estuaries Project for modeling and assessment of these systems. On-going monitoring (post-MEP) is being used to gauge changes in these systems as nitrogen management alternatives are implemented, thus supporting adaptive management. This recent activity builds on the on-going tracking of water quality relative to inlet management that has been in effect since the beginning of the program.

Over the past decade, the Town of Falmouth has intensified its efforts to deal with the problem of estuarine impairment via nitrogen enrichment. Falmouth was fully engaged in the Massachusetts Estuaries Project (MEP), through the Coastal Systems Program-SMAST at UMass Dartmouth, to conduct a quantitative assessment of habitat quality in each of the Town's estuaries and to determine appropriate nutrient thresholds for restoration of these estuaries (essential for the Town's nitrogen management planning efforts). The MEP analysis of the above mentioned six estuaries was based in part on the baseline nutrient related water quality data collected under the PondWatch program, which continues to present. The relevant data required for the MEP assessment was provided to the Town in the MEP Nitrogen Threshold Reports. However, since these reports were completed previously, the nitrogen related water quality data only carried through 2003-2004. In 2014, the Town of Falmouth contracted with the Coastal Systems Program (CSP-SMAST) to update the nutrient related water quality baseline database used by the MEP to include all the Falmouth PondWatch water quality data collected since completion of the MEP analyses. Two separate technical memoranda were developed. The first updated the water quality baseline record for West Falmouth Harbor, Bournes Pond and Little Pond (2004-2012). The second technical memorandum updated the water quality baseline for Oyster Pond, Great Pond and Green Pond (2004-2014).

This Technical Memorandum has been developed to:

1. update and extend the water quality baseline to include the results of the summer 2017 PondWatch monitoring,
2. complete a trend analysis specific to data from each of the six estuaries,
3. complete a comparison of post-MEP water quality to historic (pre-MEP) total nitrogen, salinity and chlorophyll concentrations,
4. compare water quality conditions in Bournes Pond (site of ongoing oyster aquaculture) to other nearby and similarly structured estuaries,
5. serve as a baseline for quantifying the potential effects of oyster filtration on water column nutrient and chlorophyll concentrations as well as sediment-water column nutrient dynamics should large scale aquaculture deployments be undertaken.

The data presented herein is to provide a consistent citable data source from which to track improvements in these 6 estuaries relative to MEP TN thresholds as developed by the MEP and codified as TMDLs by the MassDEP, as management alternatives are implemented in coming years.

Description of the Falmouth PondWatch Program: The Town of Falmouth has long recognized the potential threat of nutrient over-enrichment of its coastal salt ponds and embayments. In the mid-1980s the Town enacted an innovative Nutrient Overlay By-law that tied watershed development to water quality within the adjacent embayment. The goal was to keep nitrogen concentrations in the receiving systems below thresholds to prevent impaired water quality. The water quality monitoring program, Falmouth PondWatch, was initially established to provide on-going nutrient related embayment health information in support of the

By-law. The Falmouth PondWatch Program is the longest continuously running research based nutrient related water quality monitoring program in existence in the New England region. The program was initiated in 1987 to address citizen concerns over perceived declining water quality in the Town's coastal salt ponds and embayments. Adapting basic research approaches, the program's initial goal was to involve trained citizen volunteers in the near simultaneous collection of comprehensive high quality data from a large number of sites (35 at present) under the same conditions of weather and tide in multiple estuaries. Such synoptic sampling would allow for comparison of water quality data across stations and across estuaries. With these comprehensive data sets, more intensive whole-ecosystem studies of Falmouth's impaired estuaries could be undertaken to compliment the monitoring program and guide the Town towards watershed based nitrogen management and estuarine restoration. The PondWatch Program was one of the first in the Commonwealth to focus on collecting long-term, quantitative data on nutrient related water quality in coastal environments.

The Town of Falmouth was a partner in the establishment of the PondWatch Water Quality Monitoring Program to collect baseline water quality data in specific south coast systems (West Falmouth Harbor, Oyster Pond, Little Pond, Great Pond, Green Pond, Bourne Pond). The town, in collaboration with researchers now at the Coastal Systems Program at SMAST (but who were previously located at the Woods Hole Oceanographic Institution), had partial funding from WHOI Sea Grant. PondWatch proved capable of collecting research quality data on small estuaries using trained volunteers, won numerous national awards and has served as the model for the subsequent monitoring programs that now cover most of the estuaries in the Commonwealth. The Program has supported dozens of management studies for the Town, including MEP nitrogen threshold reports and MassDEP TMDL's, in addition to numerous published research papers disseminating the information to the greater ecological community. Presently, the program is geared towards compliance monitoring as the Town moves beyond the MEP nitrogen threshold development phase and into implementation of nitrogen management actions to meet MassDEP/USEPA established TMDL's. To date, the program has been conducted by SMAST and PondWatch volunteers since 1997, with the Town of Falmouth renewing the partnership in 2016. The present effort provides a mechanism to continue the PondWatch post-MEP monitoring while keeping the data up to MEP Quality Assurance levels and providing the Town with a single consistently collected and analyzed dataset for its estuarine management efforts.

When the PondWatch Program was first started, the first three Ponds to undergo water quality monitoring in the Town of Falmouth were Oyster Pond, Little Pond and Green Pond. Monitoring was primarily initiated for making an initial assessment and for planning purposes as development within coastal watersheds had been rapidly progressing (1980' and 1990's). This initial effort was closely linked to the Town of Falmouth Planning Department relative to the Town's new (1980's) Nutrient Overlay Bylaw. The initial effort later grew to develop refined tools for gauging future nutrient effects from changing land-uses. The GIS database used in the MEP studies completed throughout the Town's estuaries is part of that continuing effort. Over time the PondWatch Water Quality Monitoring Program expanded to also collect water quality data from Great Pond, Bourne's Pond and West Falmouth Harbor. Because of these efforts, all PondWatch estuaries have completed Massachusetts Estuaries Project assessments and have USEPA accepted TMDL's (under the Clean Water Act) to support the Town of Falmouth's on-going restoration efforts.

Through this unique partnership between citizens, scientists, regulators and local government, information gained from the research is being swiftly and directly applied toward effective management decisions for these fragile coastal environments. Long-term monitoring is particularly important in our coastal embayments as it may take years to decades before activities occurring in watersheds have a measurable impact on these coastal systems. The consistent and continual water quality and ecological monitoring sustained by the PondWatch volunteers is particularly valuable in that, in addition to the routine sampling, it provides long-term nitrogen related water quality metrics to support a variety of ecological response analyses (infauna, eelgrass, macroalgae) presently being conducted by SMAST researchers across southeastern Massachusetts embayments. This comprehensive water quality and habitat information is crucial to developing appropriate long-term management plans, verifying standards, and furthering scientific understanding of the ecological processes that ultimately structure these environments.

The specific objectives of the Falmouth PondWatch Program continue to be:

- to provide a long-term data base of nutrient levels and environmental conditions on Falmouth's coastal salt ponds required for data-based management;
- to form the basis for the development and evaluation of various potential management and remediation options;
- to provide a high quality independent evaluation of the impacts of both natural and man induced alterations (e.g. changes to nutrient inputs or circulation) to pond water quality.
- to evaluate the effectiveness of implemented management programs aimed at protecting or improving nutrient related water quality and provide compliance monitoring in support of nitrogen TMDLs developed by the MassDEP post-MEP;
- to provide necessary data to evaluate impacts of the Falmouth Wastewater Treatment Facility on West Falmouth Harbor, and potential impacts from nutrient plumes emanating from the Mass Military Reservation on Bournes, Green and Great Ponds;
- to develop heightened public awareness of the cumulative impact of human activities on these ponds through interactive partnerships between citizens, scientists and resource managers to preserve the ecological health of these fragile coastal ecosystems.

Providing critical environmental data for identifying ecological degradation, isolating the causes of decline and developing management / remediation plans, the Falmouth Pondwatchers have set themselves apart from many monitoring programs in their mission to collect research-quality data for development of scientifically based management plans. After 28 years of monitoring, data from the program has been heavily utilized for guiding management decisions, notably reconstruction of the Little Pond culvert, modifications to the Green Pond Bridge, construction of the Oyster Pond Weir, and monitoring of potential impacts from the nutrient plumes from the Massachusetts Military Reservation (Bournes, Great and Green Ponds) as well as the plume from the Falmouth Wastewater Treatment Facility (West Falmouth Harbor). The importance of these long-term data sets cannot be overstated, taking into account year to year and site to site variations as well as allowing for long-term evaluation of various remediation measures. The PondWatch has continued to fulfill new needs as they arise including, TMDL compliance monitoring and assessment of innovative nitrogen management approaches being investigated by the Town of Falmouth (e.g. oyster culture). Finally, there has been an unforeseen benefit of this approach, the unique partnership which has developed between citizens, regulators and scientists, facilitating the development of cost effective yet environmentally sound management strategies. This partnership is essential as the Town moves forward with implementation of its estuarine management plans.

Unfortunately, the continual monitoring through PondWatch has documented that many regions within the Town's coastal ponds continue to show water quality declines and are beyond the limits set by the historic nutrient By-law as well as the MEP developed embayment specific nitrogen thresholds and resulting USEPA/MassDEP Nitrogen TDML limits. In this context, the Coastal Systems Program was tasked with completing a summary of all the nutrient related water quality that has been collected in the estuaries monitored through the PondWatch Program for comparison to the estuarine specific nitrogen thresholds established through the MEP, keep the database current via annual updates and use the database to make inter-estuarine comparisons of water quality in Bournes Pond and others as a back drop for understanding the efficacy of oyster propagation as an in situ method for enhancing nutrient related water quality.

Per agreements with the Town of Falmouth to keep the water quality database up-to-date, the PondWatch data that is summarized in this Technical Memorandum is that which was collected post completion of the MEP analysis (2004/2005) for the six named estuaries above and compares data collected from sampling to 2017 to data collected up to 2012 as previously summarized in earlier memos submitted to the Town of Falmouth. The data has been assessed relative to the long-term (MEP) baseline and a trend analysis conducted on key metrics (TN, Chlorophyll-a, salinity and other relevant parameters as available). The component nitrogen forms and inorganic N & P have been included in the electronic spreadsheet containing all the data, consistent with the scope of work. The baseline assessment data for Bournes Pond, Great Pond, Green Pond, Little Pond, Oyster Pond and West Falmouth Harbor through 2017, is presented in graphical and tabular form to the Town, along with the complete QA'd database post-MEP provided electronically as a MS Excel spreadsheet.

The overall effort is specifically aimed at analysis and QA of PondWatch field and laboratory samplings, compiling and processing recent (2015-2017) PondWatch data and assessing temporal and spatial trends in key metrics associated with nutrient related water quality. This Technical Memorandum evaluates the 2016/2017 data relative to the 2004/2005-2014 summary of water quality data completed in 2014/2015. Additionally, data gaps were identified for future improvement of the monitoring program, trends assessed, the meaning of the different water quality parameters is explained and the present state of each estuary is assessed relative to the MEP nitrogen thresholds analysis. As relevant, the baseline and trends related to TMDL compliance are discussed and an inter-estuarine comparison of water quality conditions is provided with specific focus on Bournes Pond as it is currently the site of intensive testing of oyster propagation relative to large scale deployments to enhance water quality.

Compiled/tabulated Pond Watch sampling data for critical water quality parameters (2004/2005 - 2014 + 2015, 2016 and 2017) is included in summary tables as an attachment (1) to the Memo and the full database provided electronically as an integrated Microsoft Excel spreadsheet. In addition, latitude and longitude coordinates for each named sampling station has been provided (Attachment 2).

As part of PondWatch, the following measurements are typically conducted on each sampling date at each sampling station and form the water quality database utilized as a baseline for the MEP water quality modeling effort. The measurements also constitute the core data set for TMDL compliance monitoring as the Town of Falmouth moves forward with implementation of nutrient management strategies (O = On Site; L = Lab):

Physical Measurements:

(O) Total Depth
(O) Temperature
(O) Light Penetration (Secchi disk)

Chemical Measurements:

(L) Nitrate + Nitrite
(L) Ammonium
(L) Dissolved Organic Nitrogen
(L) Particulate Organic Nitrogen

(L) Total Nitrogen
(L) Chlorophyll
(L) Phosphate
(O) Dissolved Oxygen
(L) Salinity

In addition, PondWatchers record observations of pond state, weather and wind conditions, and any other pertinent information which may later prove useful to interpretation of the data such as algal blooms, fish kills or unusual odors. A detailed description of water quality in each pond is provided below.

POND SPECIFIC WATER QUALITY SUMMARIES

Summary of Nutrient Related PondWatch Water Quality Data – Bournes Pond (2004-2012, 2013, 2014, 2015, 2016, 2017)

Bournes Pond (Figure 1) exchanges tidal water with Vineyard Sound through a single armored inlet. The Bournes Pond watershed is relatively small and only moderately developed and while the inlet is undersized, restricting tidal flows, it still allows significant tidal flushing in the lower portion of the pond. The result is that the upper reaches of Bournes Pond are significantly impaired by nitrogen enrichment, but the lower reaches continue to support infaunal habitat and some eelgrass. The Sentinel Station (B-3) has a nitrogen threshold of 0.45 mg TN/L with a secondary threshold of <0.42 mg TN/L in Israel's Cove.

The TN time-series indicates that TN at all embayment stations (e.g. excluding B-5) has been increasing since the MEP assessment and update to 2014. Equally important monitoring from 2008 to 2017 indicates TN levels at the sentinel station to be >0.70 mg/L, well over the TMDL threshold (Figure 2). There has been some interannual variation with TN levels reaching a recent low in 2016 but rebounding in the upper reaches in 2017. Focusing on station B-3 (MEP sentinel station), it should be noted that average TN levels (Table 1) for the period 2004 to 2014 were the same (0.760 mg/L) as for the period 2015 to 2017 (0.76 mg/L). But average TN levels for both periods were higher than the baseline average TN concentration (0.67 mg/L) established by the MEP based water quality data collected from 1989 to 2003 (n=105). While the increases from 2004-2017 were relatively modest and the rise gradual, it did appear consistent with the rate of change in nitrogen loading to the Bournes Pond watershed over the past 15-20 years. It is important to consider that increasing / decreasing TN levels are also related to changes in tidal flow as these can be short-term and change quickly (e.g. storms, inlet dredging).

Flow from Vineyard Sound into Bournes Pond may have increased slightly in 2016 as average station salinities in 2016 (28-31 ppt excluding B-1, all station average 29.7 ppt) appeared higher compared to the 2004-2012 average salinity (27-30 ppt excluding B-1, all station average 28.8 ppt {Attachment 1, Table A}). The slightly higher salinity in Bournes Pond would indicate that water from the Sound that contains low TN concentrations which would slightly dilute the water in Bournes Pond is lowering TN levels. Conversely, in 2017 average salinity across all stations except station B-1 appeared slightly lower (25-31 ppt, all station average 28.5 ppt) compared to salinity levels for the period 2004-2012 (27-30 ppt) and there was an observable increase in TN levels in 2017. Since there is a measurable difference in salinity at the stations and since salinity typically increases with increases in tidal exchange (Attachment 1, Table A), at present we conclude that the small TN decrease in 2016 results mainly from slightly improved flushing whereas the slight increase in 2017 TN levels derive from a decrease in flushing (plausible considering how dynamic and sensitive inlets are to sediment transport and deposition) or possibly higher freshwater inflows in a high rainfall year.

The TN levels system-wide appear to be rising slightly since 2004, although the rise is variable. All stations are higher in 2004-2014 than the MEP baseline TN values, and all stations except B5 are also higher in 2015-2017 than pre-2004 (Table 1). Stations B1, B2, B3 and B6 show increased TN averages in 2015-2017 since 2004-2014 while the other stations show a lower average for the 2015-2017 period than 2004-2014. In addition, Bournes Pond has been consistently higher in TN than the threshold and the habitat impairments reflect the elevated nitrogen levels. Linear regression of TN on Sentinel Station (B-3) did not show a significant annual temporal trend (R^2=0.162), though there appears to be a slightly increased TN when comparing the average level for the period 2004-2012 (0.74 mg/L) vs. the period 2013-2017 (0.81 mg/L). Additionally, the average level for the period 2013-2017 is higher compared to the pre-2004 MEP baseline (0.670 mg/L).

Phytoplankton biomass/bloom activity has also been relatively unchanged from 2004-2017, and relatively high (average T-pigment levels 11.5, 12.4, 11.1 ug/L for 2004-2012, 2016, 2017 respectively, Figure 3). The level of chlorophyll-*a* and TN remain consistent with the level of habitat impairment noted previously by the MEP. There is no evidence of habitat improvement within this estuary and none is expected based on the water quality metrics.

Considering the most recent TN and salinity data, the temporal pattern of change in key water quality metrics suggests a rapid response in water quality once nitrogen management alternatives (tidal flushing, nitrogen load reduction) are implemented with increased tidal flushing likely driving the most rapid response.

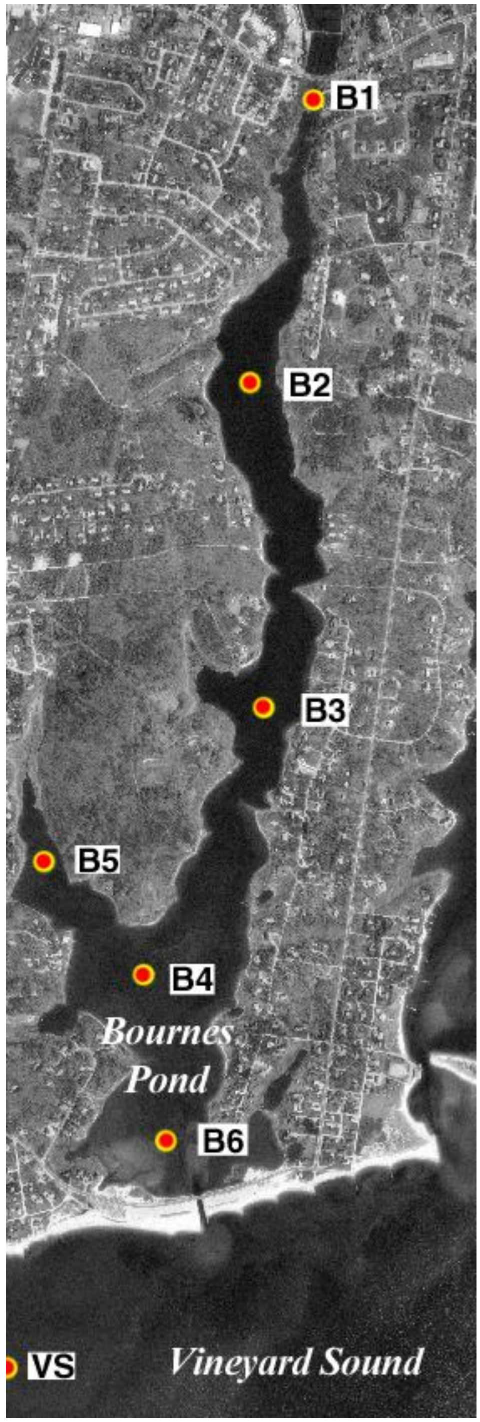
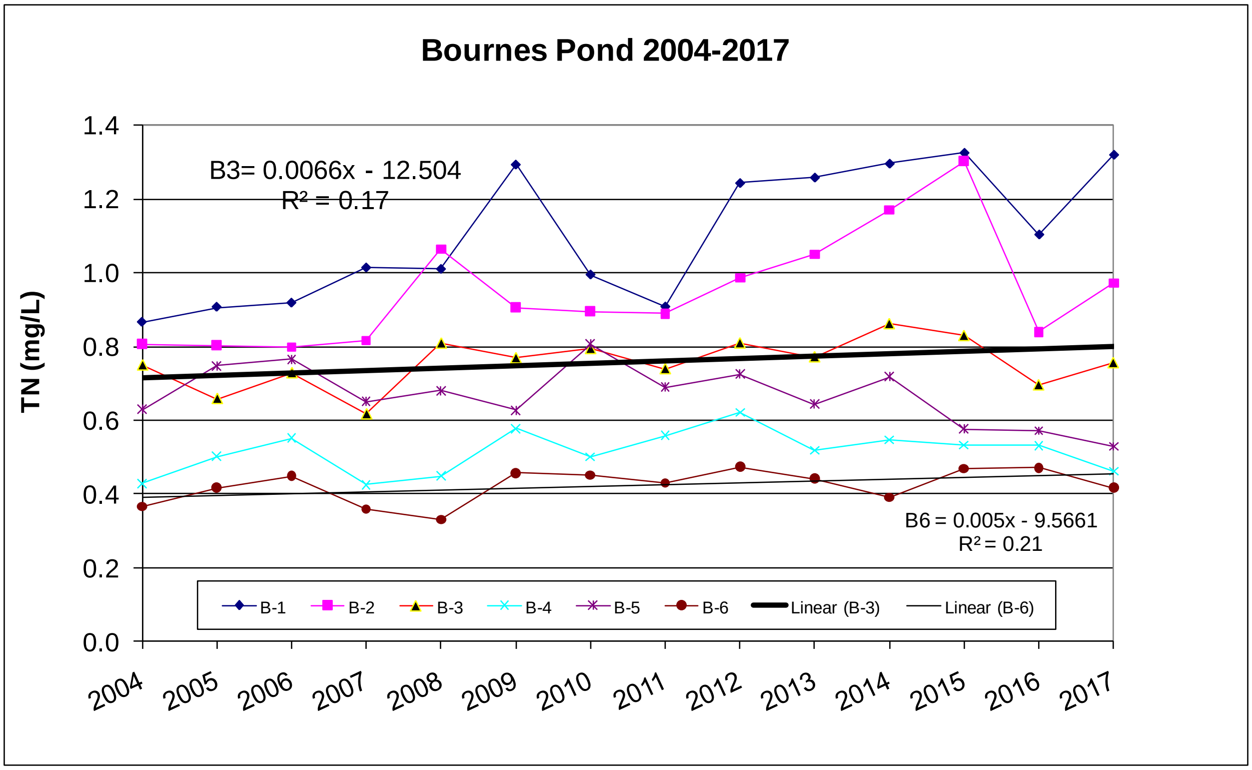


Figure 1. Bournes Pond water quality sampling stations for SMAST-PondWatch 2004-2017 and nutrient related water quality baseline used in the Massachusetts Estuaries Project (MEP) analysis.



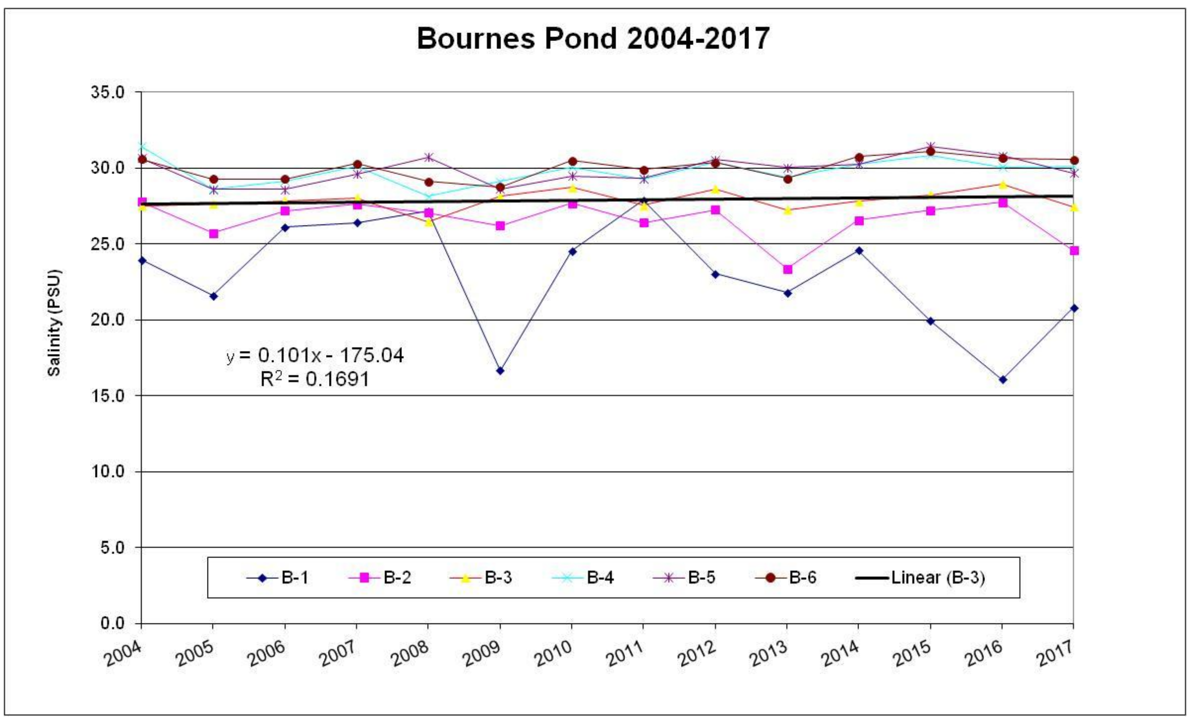


Figure 2. Annual averages for Bournes Pond nutrient related water quality post-MEP analysis 2004-2017 from SMAST-PondWatch for stations shown in Figure 1. Top: TN station averages. TN threshold 0.45 mg/L at sentinel station B-3 and <0.42 throughout the lower 1/3 of estuary to support eelgrass restoration. System remains above the TN threshold. Bottom: Salinity station averages. General gradient of fresher (inner) to more marine (outer) basins.

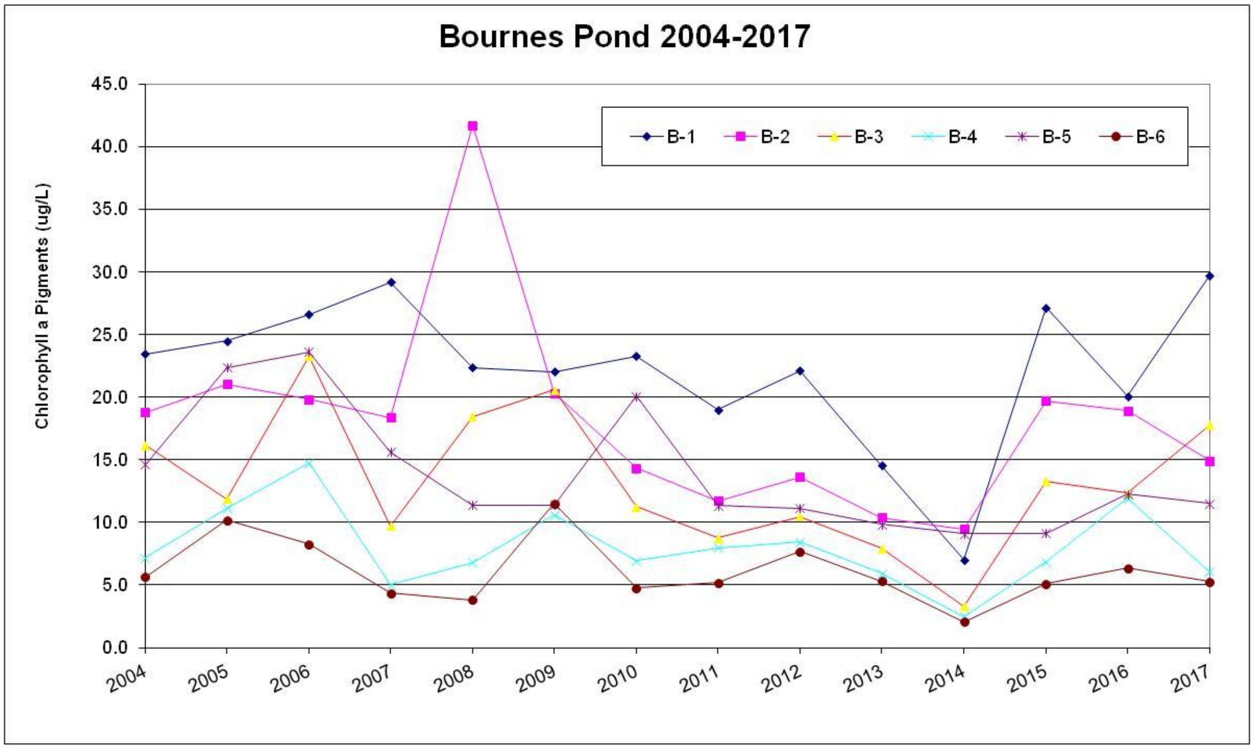


Figure 3. Annual averages for Bournes Pond nutrient related water quality post-MEP analysis 2004-2017 from SMAST-PondWatch for stations shown in Figure 1. Total chlorophyll-*a* pigment as indicator of phytoplankton biomass. Averages >10 ug/L are indicative of nitrogen enrichment.

Table 1. Bournes Pond total nitrogen (TN, mg N/L) averages by period. MEP is data prior to 2004. Sentinel Station B-3 has a TN threshold of 0.45 mg/L.

Bournes	**TN 2004 - 2014**			**TN**	**2015 - 2017**		**TN**
Station	**mean**	**s.d.**	**N**	**mean**	**s.d.**	**N**	**MEP**
B1	1.037	0.228	41	1.250	0.290	12	**0.928**
B2	0.927	0.228	85	1.038	0.445	24	**0.880**
B3	**0.755**	**0.189**	**80**	**0.760**	**0.144**	**24**	**0.670**
B4	0.514	0.123	87	0.507	0.096	23	**0.482**
B5	0.699	0.144	87	0.558	0.073	23	**0.674**
B6	0.415	0.073	86	0.452	0.085	23	**0.387**

Summary of Nutrient Related PondWatch Water Quality Data – Great Pond (2004-2012, 2013, 2014, 2015, 2016, 2017)

Great Pond (Figure 4) exchanges tidal water with Vineyard Sound through a single armored inlet. The Great Pond watershed is relatively small and dominated by residential development. The inlet is maintained by the Town of Falmouth and generally allows significant tidal flushing, as evidenced by the relatively short system residence time of estuarine waters. It appears that the tidal inlet is sufficiently maintained to not cause water quality impairments within Great Pond, as tidal exchange with Vineyard Sound serves to lower overall nitrogen levels. However, Great Pond remains impaired in its upper reaches and tributary basin (Perch Pond) by nitrogen inputs from its watershed even in its well flushed condition. The Sentinel Station (GT-5, in the lowermost tidal river reach) established by the MEP has a nitrogen threshold of 0.40 mg TN/L, and MEP modeling indicated that nitrogen concentrations in the lower main basin could reach <0.30 mg TN L^{-1} when the threshold at station GT-5 is met. This indicates that significant eelgrass habitat restoration would occur within the regions of the 1951 eelgrass coverage.

Continued monitoring by PondWatch since 2004 have consistently found TN levels above the threshold needed for restoration of water quality and associated infauna and eelgrass habitat. This is expected as there have been no significant nitrogen management actions that would affect estuarine nitrogen levels. In fact, TN levels appear to have been relatively stable with interannual variations making any trends difficult to quantify for all stations (Figures 5). Examination of pre-2004 versus 2004-2014 (previous analysis) and 2015-2017 (new data) TN levels does suggest that there has been a small increase in TN at each estuarine station in Great Pond (GRT-2,3,5,6) and Perch Pond (GRT-4) in the recent decade (Table 2), but TN levels appear unchanged between 2004-2014 and 2015-2017. The average TN concentration (GRT-2,3,4,5,6 combined) pre-2004 was 0.740 mg/L compared to 0.882 mg/L for the period 2004-2014 and 0.875 mg/L in the period 2015-2017. All TN data collected by PondWatch for Great Pond have documented that TN has remained elevated and well over the level supportive of high water quality and continues to present (2013-2017 annual means: 0.939, 0.735, 0.928, 0.820, 0.900 mg/L) with a parallel increase in total pigment (Figures 5 and 6). The linkage between nitrogen and phytoplankton production can be seen in the parallel inter-annual changes in chlorophyll-*a* levels with TN (more TN, more CHLA, Figure 6). In contrast salinity levels have remained relatively constant throughout much of the estuary, although the uppermost stations adjacent the discharge from the Coonamessett River show inter-annual variations (Attachment 1, Table B and Figure 5 bottom) particularly for the period 2006-2008. A closer examination of the TN and chlorophyll-*a* data shows the level of inter-annual change where over a six year period (2012-2017), levels of these key metrics appeared to decline for a few years (2012-2014) but then rebound in 2015, decline in 2016 (only TN) and rebound in 2017. This emphasizes the need for long term monitoring for determining real changes versus annually driven events. Additional investigation is underway to compare the maintenance dredging schedule for the inlet to the variation in TN levels measured in the preceding and following summers, as the variability observed over the period 2012 to 2017 maybe due to changes in the flushing through the inlet. This information is important, since it would indicate that a targeted inlet maintenance program for nitrogen management could help to offset some of the changes in watershed N loading.

Overall, it appears clear that Great Pond has not improved since 2004 and that all water quality metrics and particularly TN, chlorophyll-a and oxygen continue to document a nitrogen impaired system, mainly in the upper tributary (Coonamessett River estuarine reach, GRT-1 to GRT-3) and Perch Pond (GRT-4). Most significant to the habitat quality in this estuary is the observed elevated levels in TN greater than 0.80 mg N/L since 2004 (Figure 5). It would be useful to better determine the causes of the observed interannual variation in TN to allow a more sensitive determination of water quality changes once management actions are taken.

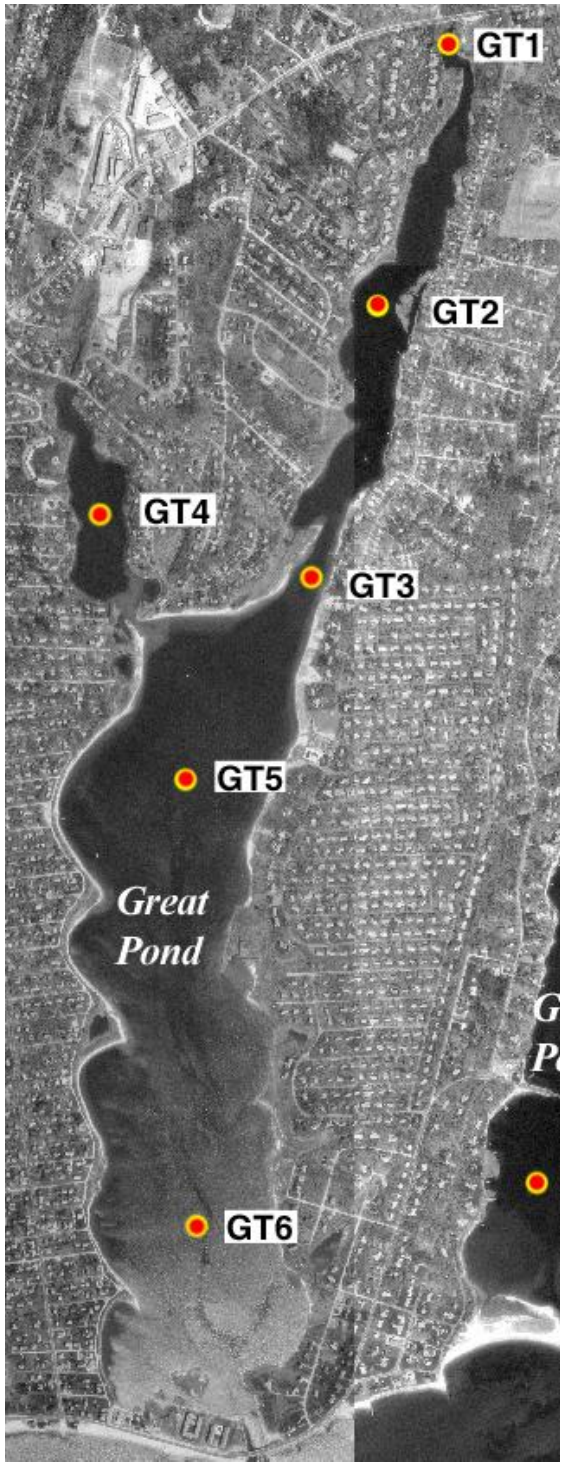


Figure 4. Great Pond water quality sampling stations for SMAST-PondWatch 2004-2017 and nutrient related water quality baseline used in the Massachusetts Estuaries Project analysis.

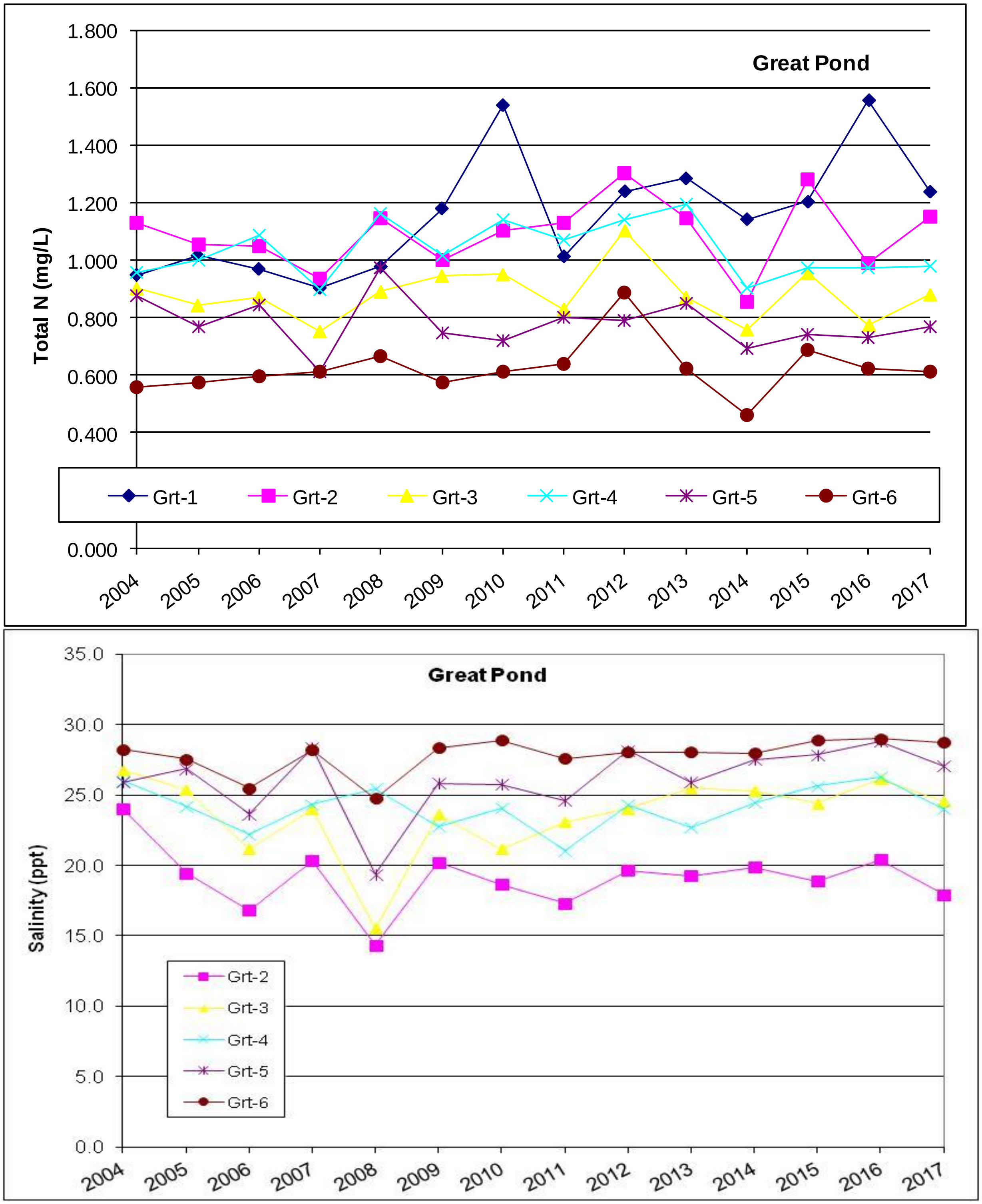


Figure 5. Annual averages for Great Pond nutrient related water quality post-MEP analysis 2004-2017 from SMAST-PondWatch for stations shown in Figure 4. Top: TN station averages. TN threshold at sentinel station (GT-5) is 0.40 mg/L. System remains above the TN threshold. Bottom: Salinity station averages. General gradient of fresher (inner) to more marine (outer) basins.

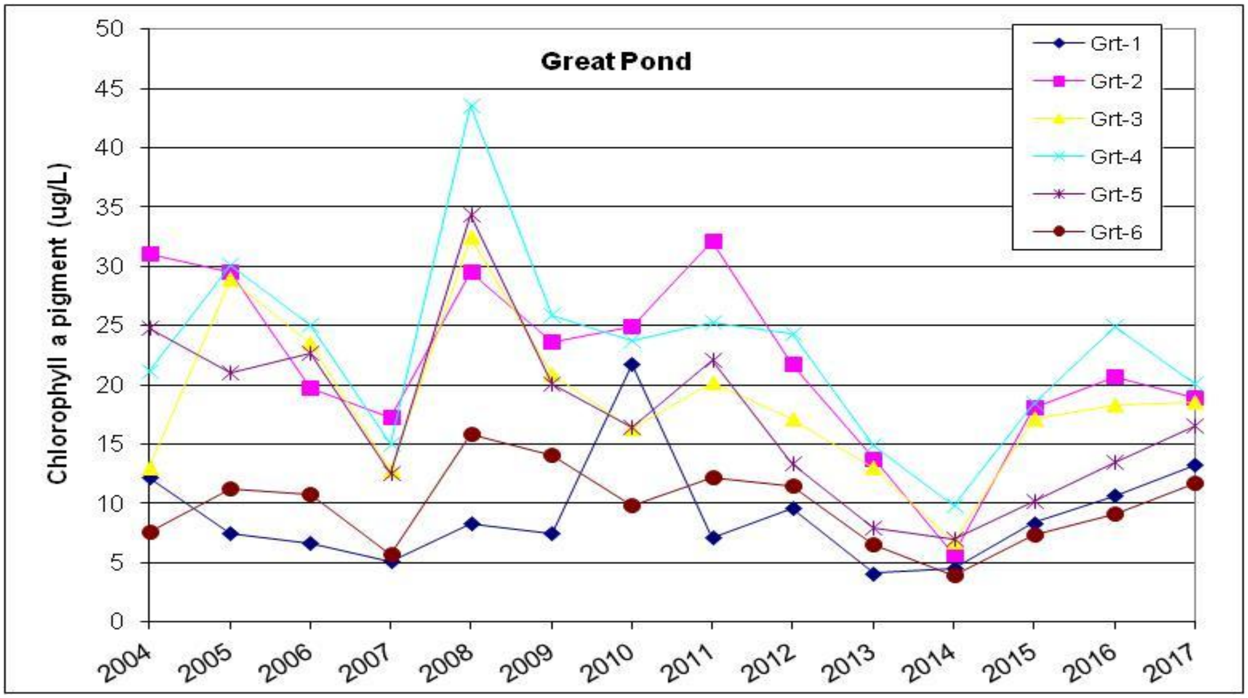


Figure 6. Annual averages for Great Pond nutrient related water quality post-MEP analysis 2004-2017 from SMAST-PondWatch for stations shown in Figure 4. Total chlorophyll-*a* pigment as indicator of phytoplankton biomass. Averages >10 ug/L are indicative of nitrogen enrichment.

Table 2. TN values (mg N/L) in Great Pond from 2004-2014, 2015-2017 and MEP averages pre-2004.

Great Pond	2004 - 2014			2015-2017			MEP
Station	**Mean**	**s.d.**	**N**	**Mean**	**s.d.**	**N**	**Mean**
Grt1	1.106	0.235	42	1.334	0.283	12	0.855
Grt2	1.075	0.238	86	1.136	0.264	24	0.881
Grt3	0.885	0.226	86	0.871	0.239	24	0.739
Grt4	1.041	0.272	85	0.976	0.235	24	0.895
Grt5	0.788	0.186	85	0.748	0.161	24	0.644
Grt6	0.619	0.167	85	0.641	0.128	24	0.543
TN values in mg N/L							

Summary of Nutrient Related PondWatch Water Quality Data – Green Pond (2004-2014, 2015, 2016, 2017)

Green Pond (Figure 7) exchanges tidal water with Vineyard Sound through a single armored inlet. The Green Pond watershed is relatively small, but is highly developed with mainly commercial and residential property using on-site septic disposal of wastewater. Based on the MEP analysis of Green Pond (2004), water quality data indicates a system which is significantly nitrogen impaired throughout its upper half, based primarily upon the very high chlorophyll-*a* levels and periodic oxygen declines. In contrast, the lower reaches support healthier conditions (moderately impaired/significantly impaired) based upon both the level and duration of observed oxygen depletion and chlorophyll-a levels. The Sentinel Station (GP-4) has a nitrogen threshold of 0.42 mg TN/L to generate TN levels of 0.40 in the lower basin below the Menahaunt Bridge. The threshold TN level was set at 0.40 mg TN L^{-1} to restore complete eelgrass coverage of the lower basin and 0.42 mg TN L^{-1} at the Sentinel Station to re-establish the marginal eelgrass beds (both conditions are required in this system).

Green Pond has had significant nitrogen enrichment and impaired habitat for decades and the 2004-2014 and 2015-2017 periods generally showed continued high nitrogen levels with associated low dissolved oxygen and high total chlorophyll-*a* levels. There was no detectable difference in TN levels in both periods, with near perfect agreement between the individual stations (Table 3 and addendum).

Elevated TN levels in 2015 and 2016 corresponded to increased levels in total pigment above 2014 levels with a slight drop in total pigment in 2017 but still at a level above what was observed in 2014. As in previous years, TN levels throughout this linear drown river valley estuary show a strong gradient of decreasing TN and decreasing chlorophyll-*a* from the headwaters to the tidal inlet (Figures 7, 8 and 9). The 2015, 2016 and 2017 chlorophyll-*a* levels show continuing large summer blooms consistent with the high TN levels which far exceed the nitrogen threshold for this system, particularly noticeable in the upper and mid monitoring stations (GP-1,2,2A,3). While the upper reaches in 2016 reached a summer average chlorophyll level of ~30 ug/L, mid and upper stations all reached levels between 15-25 ug/L (GP-3, GP-2A and GP-2 respectively), indicative of significant nitrogen impairment. The lowermost basin (GP-5) showed summer average chlorophyll levels in the period 2015-2017 between 6-12 ug/L, indicative of a lessened level of nitrogen enrichment due to proximity to the inlet and flushing with low nitrogen water from Vineyard Sound. It appears that blooms had been lower 2011-2014 but increased in the summers 2015, 2016 and 2017, although this may relate to the sampling frequency (only 4 samplings per year) of this highly temporally variable metric.

Equally problematic for restoration of this estuary is the finding that all stations have decreased water quality, since the 2004 MEP analysis. While estuarine TN levels are currently stable, it appears that this system will not improve its resource quality without positive action to manage its nutrient levels by the Town. Fortunately, the Town of Falmouth is fully engaged in activities to restore Green Pond and its other 13 estuaries, with some management actions already in place (e.g. Oyster Pond weir, West Falmouth WWTF upgrade). Additionally, innovative alternatives are being tested and others are in the planning or even permitting phase of implementation.

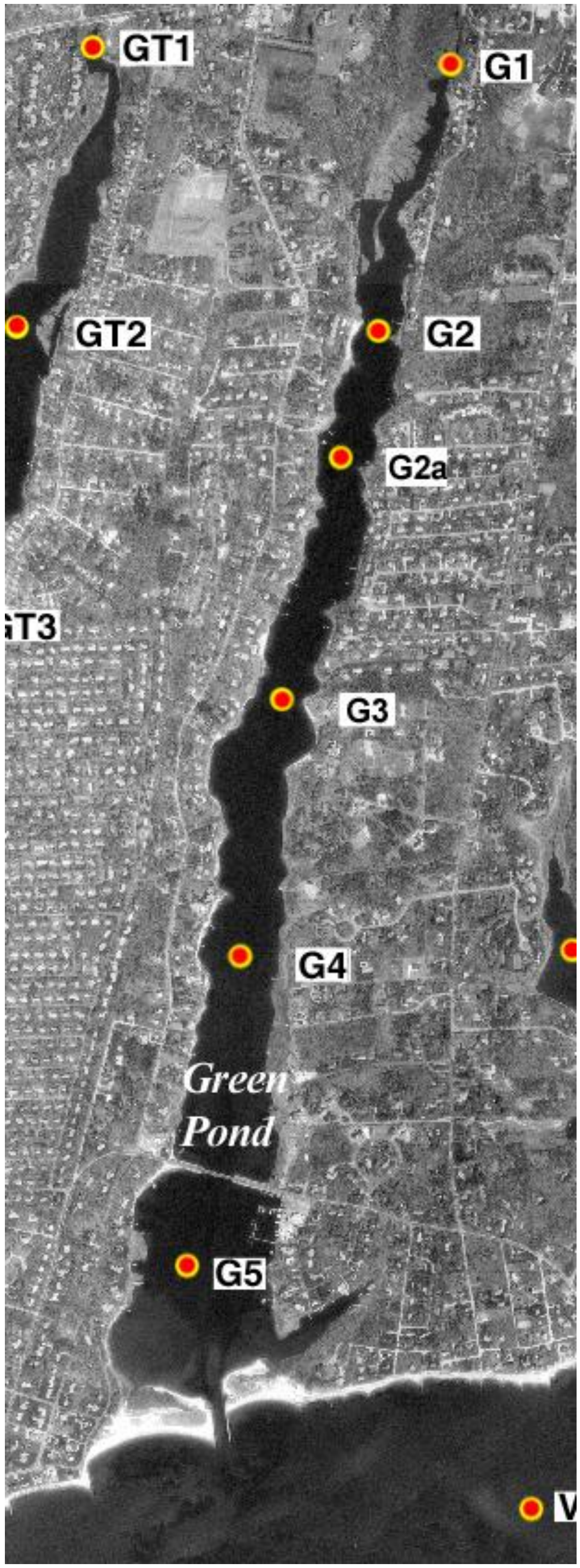
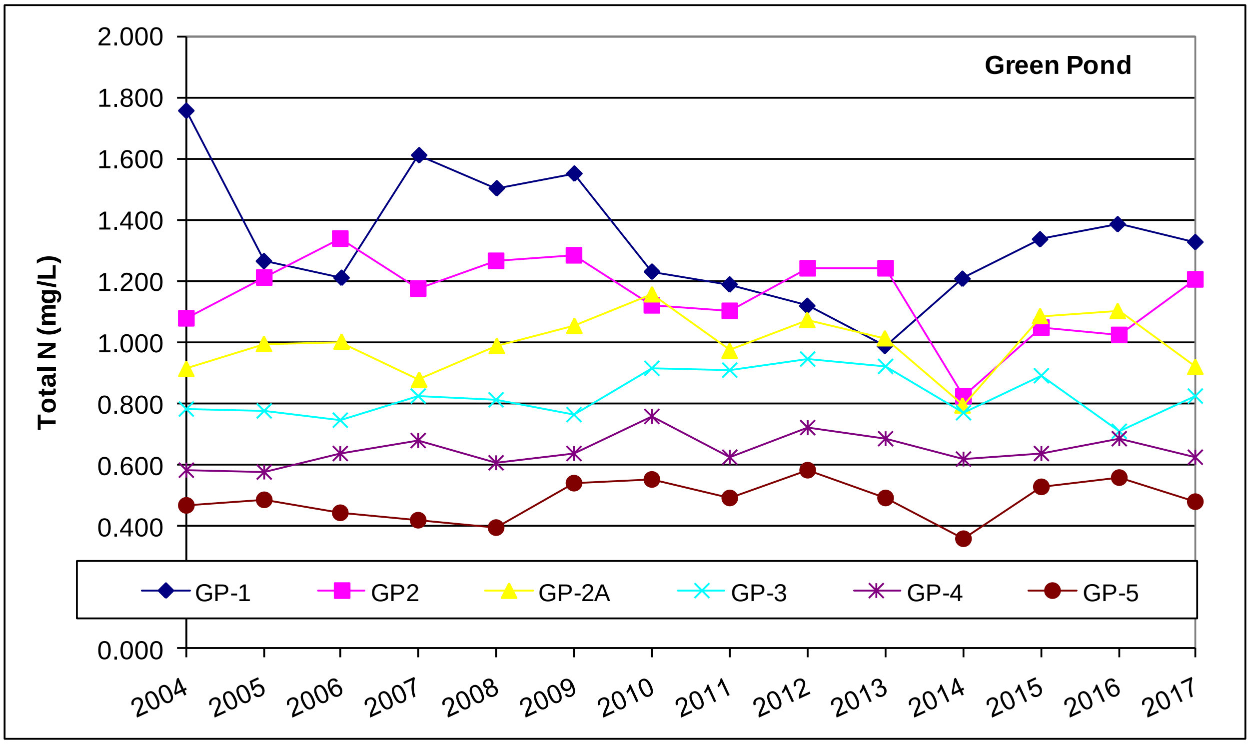


Figure 7. Green Pond water quality sampling stations for SMAST-PondWatch 2004-2017 and nutrient related water quality baseline used in the Massachusetts Estuaries Project analysis.



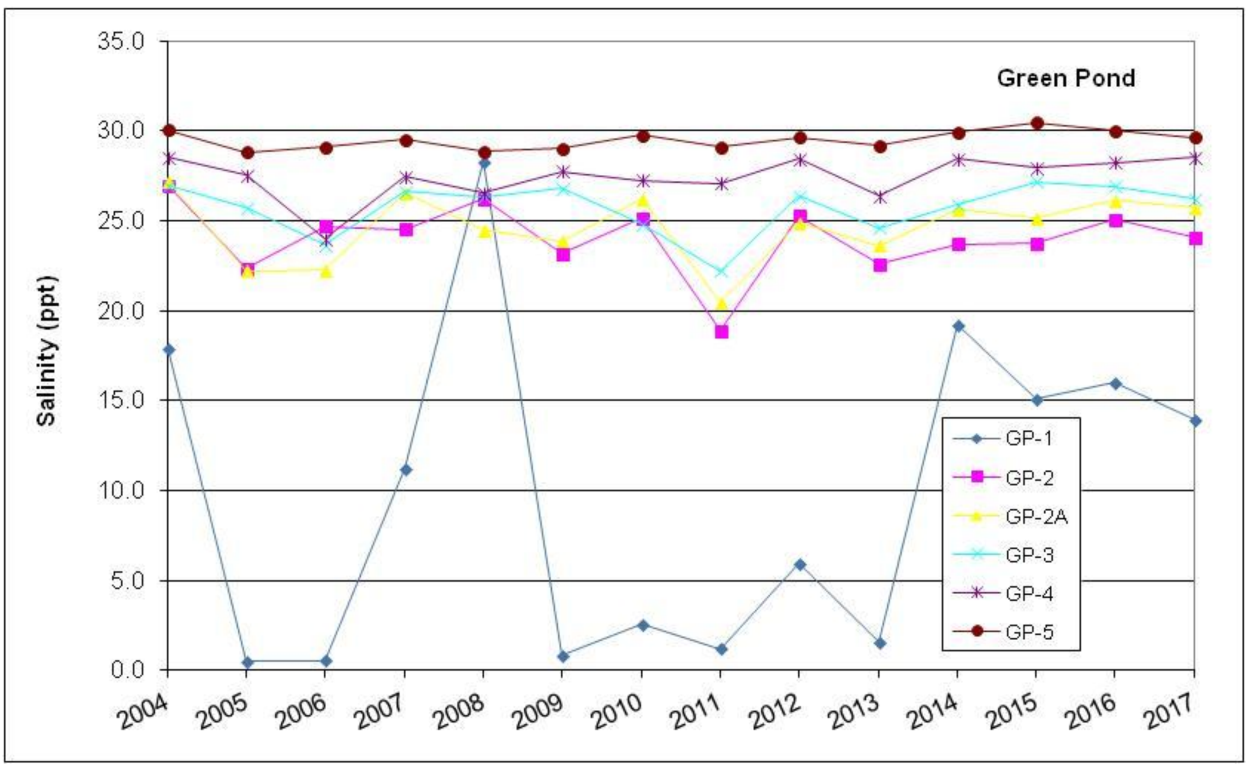


Figure 8. Annual averages for Green Pond nutrient related water quality post-MEP analysis 2004-2017 from SMAST-PondWatch for stations shown in Figure 7. Top: TN station averages. TN threshold is 0.42 mg/L to support eelgrass restoration. System remains above TN threshold. Bottom: Salinity station averages, general gradient of fresher inner to more marine outer basins. There appears to be a slight freshening in the mid (GP-3,2A) and upper (GP-2) portions of the system, likely related to occulsion of the tidal inlet.

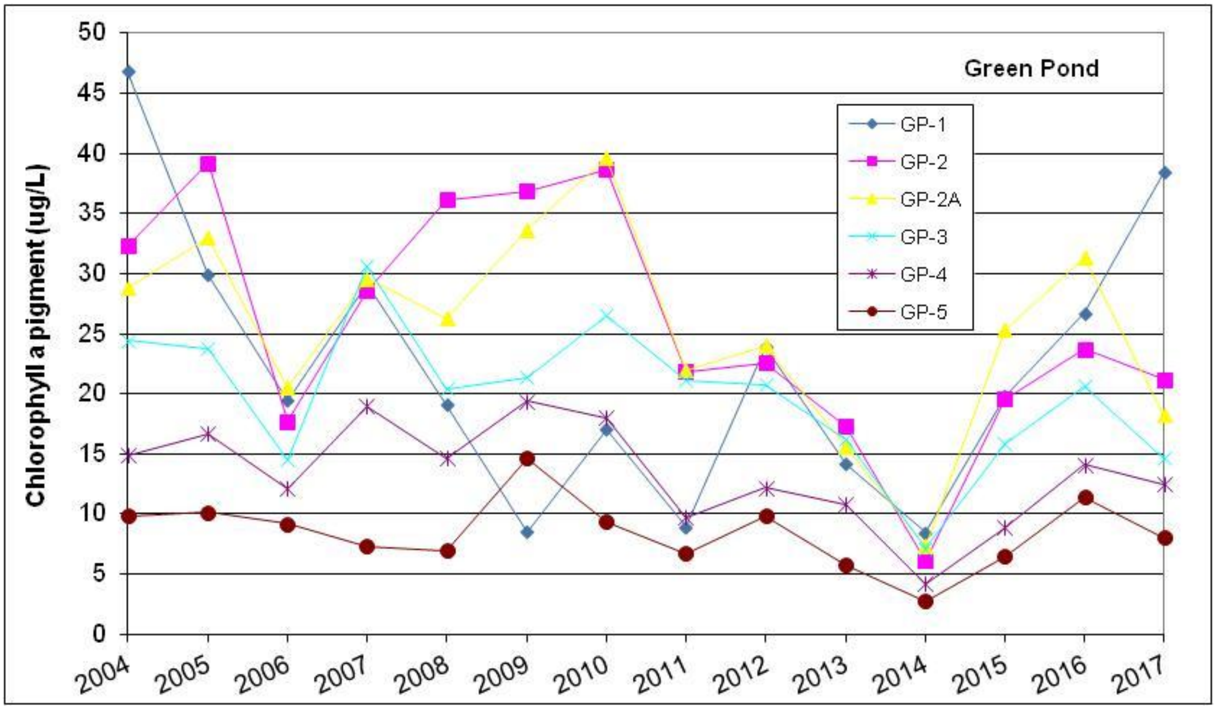
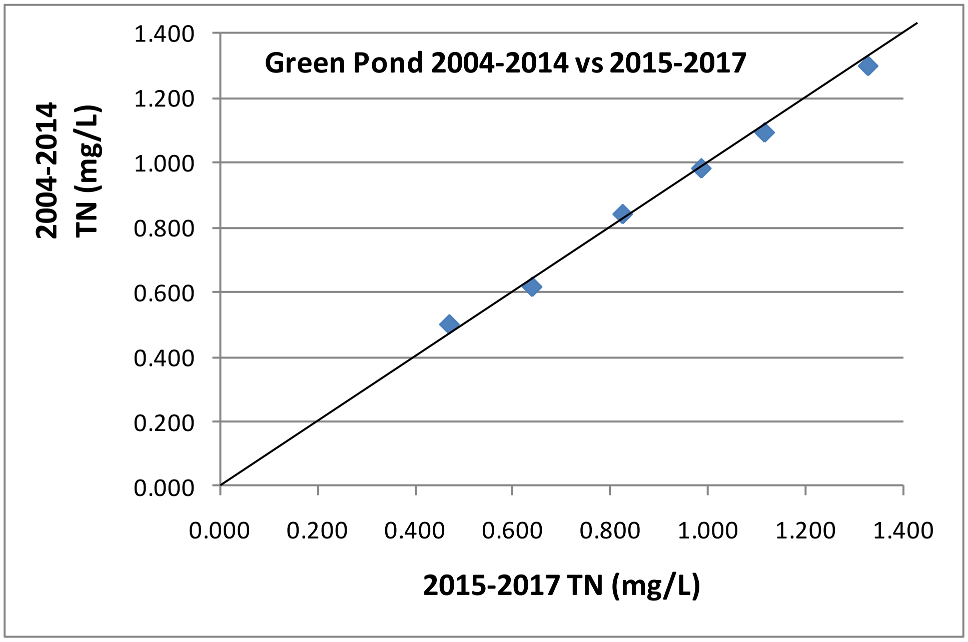


Figure 9. Annual averages for Green Pond nutrient related water quality post-MEP analysis 2004-2017 from SMAST-PondWatch for stations shown in Figure 7. Total chlorophyll-*a* pigment as indicator of phytoplankton biomass. Averages >10 ug/L are indicative of nitrogen enrichment.

Table 3. TN values (mg N/L) in Green Pond from 2004-2014, 2015-2017 and MEP averages pre-2004.

Green Pond	TN 2004-14			TN 2015-17			pre-2004
Station	**Mean**	**s.d.**	**N**	**Mean**	**s.d.**	**N**	**MEP**
GP1	1.327	0.357	43	1.300	0.327	12	1.364
GP2	1.115	0.248	81	1.095	0.254	24	0.988
GP2A	0.985	0.205	84	0.984	0.228	24	0.927
GP3	0.824	0.180	85	0.843	0.211	23	0.750
GP4	0.638	0.142	85	0.618	0.132	24	0.540
GP5	0.469	0.105	101	0.502	0.094	27	0.440



Addendum to Table 3. Plotting 2004-2014 versus 2015-2017 and comparing to 1:1 equality line shows very close agreement between the two time periods by station for Total Nitrogen, indicating the relative stability of TN levels in Green Pond since 2004, Linear regression yields a slope of 0.95 and R^2 of 0.997.

Summary of Nutrient Related PondWatch Water Quality Data – Little Pond (2005-2012, 2013, 2014, 2015, 2016, 2017)

Little Pond (Figure 10) exchanges tidal water with Vineyard Sound through a single armored inlet. The Little Pond watershed is relatively small, but is densely developed mostly with commercial and residential properties which until recently used on-site septic disposal of wastewater. As part of the Town's nitrogen management plan to restore its impaired estuarine waters, much of the watershed to Little Pond has recently been connected to the Town's WWTF (2017) removing much of the significant septic system nitrogen load to Little Pond. As this is an on-going recent event, its impact on Little Pond water quality has not yet occurred. However, in the near future, PondWatch expects to be tracking water quality improvements as "stored" septic nitrogen in groundwater is flushed out and nitrogen loading to the estuary declines.

In addition to sewering the Little Pond watershed, the water quality can also be improved by widening the undersized tidal inlet and keeping the present inlet free of sand which restricts flow periodically. Presently, and as a result of restricted flow, TN levels are causing water quality and habitat impairments resulting in the pond showing poor water quality throughout its tidal reach (LP-1, LP-2, LP-3). The Sentinel Station (LP-2) has a nitrogen threshold of 0.45 mg TN/L to support high quality habitat, which also results in TN levels of <0.42 in the lower basin (LP-3). Current TN levels remain far above these targets, but should begin to decline as the effects of sewering the watershed reach the receiving estuarine waters.

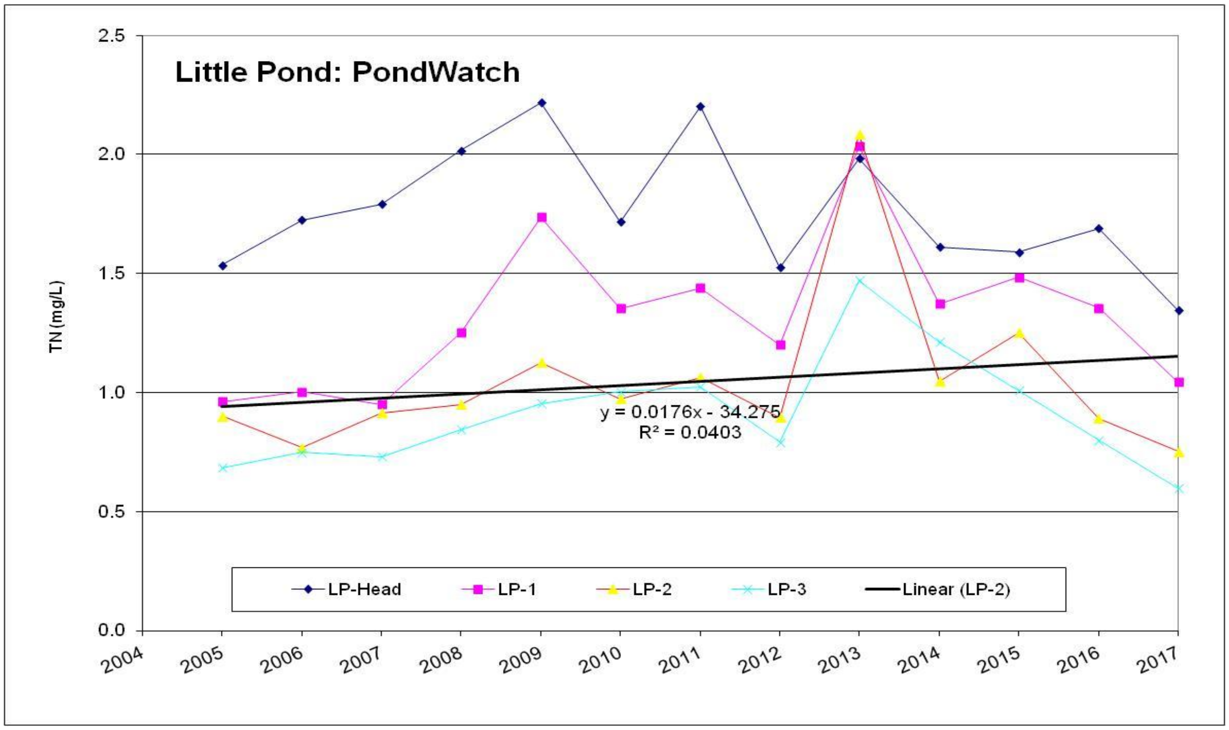
In contrast to the other estuaries, Little Pond does appear to have rapid changes in TN as can be seen in the time-series TN record (Figure 11). A rapid increase is particularly evident in the later years in the upper basin (LP-1), but at the other stations as well. Overall, the pattern is one of TN increases throughout the estuary, but this cannot be evaluated on a year by year basis, as inter-annual variation is apparent. In 2016, TN levels appeared to increase slightly at the upper stations (LP-Head and LP-1) while staying stable at LP-2 and LP-3. This may be associated with changes in watershed nitrogen inputs, but also likely linked to changes in tidal flushing affecting concentrations at the lower stations. By comparison, TN levels in 2017 appear to be lower at all stations than levels observed in 2016. Linear regression of TN on Sentinel Station (LP-2) did not show a significant (nor meaningful) annual temporal trend (R^2=0.04), consistent with the averages of pre-2004, 2004-2014 and 2015-2017 (see Table 4).

As previously mentioned, this is likely due to effective flushing of the system through the inlet to Vineyard Sound. As in previous years, variations in tidal flushing remain consistent with the observed inter-annual variation in salinity at each sampling station, which tended to be larger than observed in the other estuaries. Given the structure and location of the Little Pond inlet relative to local sand transport patterns under storm and non-storm periods, it appears that occlusion of the inlet by sand deposition and periodic clearing during periods of higher tidal velocities are linked to the variations in TN and salinity levels. This is supported by the variation in salinity, where relatively large inter-annual variations were observed and in general lower salinities at a station were coupled to higher TN levels (Figure 11). There appears to be a freshening throughout the basins in recent years likely related to occulsion of the tidal inlet. Keeping the existing inlet open and later widening it, should have a significant effect in lowering present TN levels and improving nitrogen related habitat quality within Little Pond.

Phytoplankton biomass/bloom activity did not show a clear pattern across the stations over 2005-2012 and there were no remarkable bloom events captured in the 2016 data. 2016 total pigment levels are not significantly different than levels observed in 2012 and in both cases remain well above (~14-22 ug/L) the 10 ug/L threshold indicating impairment (Figure 12). 2017 levels do appear slightly lower than 2016 observations, however, the levels remain between 10 and 20 ug/L which is still above the generally accepted impairment threshold. It appears that blooms were larger in the first part of the record (2004-2010), although this may relate to the lower sampling frequency (only 4 samplings per year) in the more recent summer sampling seasons of this highly temporally variable metric, although the impact of more recent oyster deployments cannot be discounted. The restriction of tidal exchanges creates a situation somewhat like a pond, where water quality parameters show weaker gradients, i.e. tend to be more evenly distributed than in a well flushed estuary. The lack of gradient shows clearly in the chlorophyll-*a* results for some years (2011, 2012, 2014), however, in other years there does appear to be more of a gradient (2006-2008, 2015, 2016, 2017). In some cases the chlorophyll-*a* data shows a more localized bloom (e.g. 2010) that interrupts the more typical longitudinal gradient from estuary head to inlet. Nonetheless, the level of chlorophyll-*a* and TN are consistent with the level of habitat impairment noted by the MEP. There is no evidence of habitat improvement within this estuary and none is expected based on the water quality metrics.

Fortunately, the temporal pattern of change in key water quality metrics suggests a rapid response in water quality once nitrogen management alternatives (tidal flushing, nitrogen load reduction) are implemented. As in previous years, inlet management should be consistently undertaken to maintain effective exchange of water from Vineyard Sound too Little Pond, however, load reductions will likely be necessary to bring nutrient concentrations down to the threshold level at the sentinel station.

Figure 10. Little Pond water quality sampling stations for SMAST-PondWatch 2005-2017 and nutrient related water quality baseline used in the Massachusetts Estuaries Project analysis.



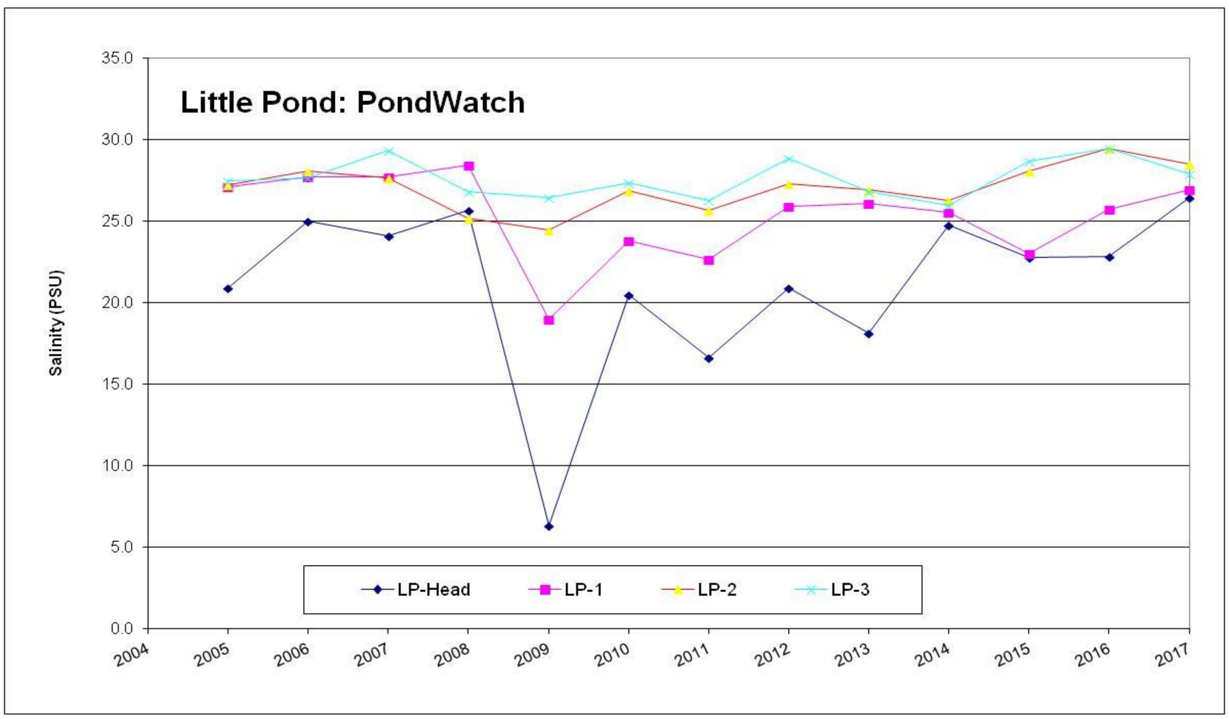


Figure 11. Annual averages for Little Pond nutrient related water quality post-MEP analysis 2005-2017 from SMAST-PondWatch for stations shown in Figure 10. Top: TN station averages. System remains above its TN threshold of 0.45 mg/L to support eelgrass restoration. Bottom: Salinity station averages at each station show general gradient of fresher inner to more marine outer basins.

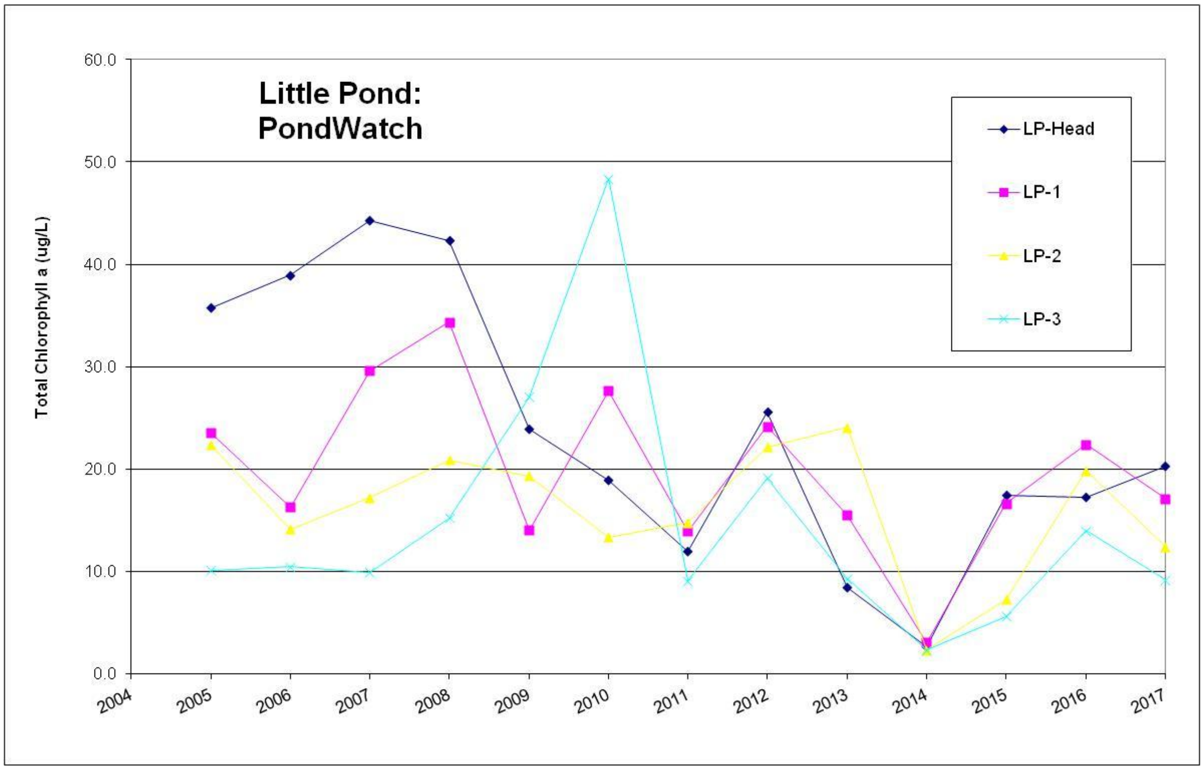


Figure 12. Annual averages for Little Pond nutrient related water quality post-MEP analysis 2004-2017 from SMAST-PondWatch for stations shown in Figure 10. Total Chlorophyll-*a* pigment as indicator of phytoplankton biomass. Averages >10 ug/L are indicative of nitrogen enrichment.

Table 4. TN values (mg N/L) in Little Pond from 2005-2014, 2015-2017 and MEP averages pre-2004. No significant consistent changes in TN were observed between the sampling periods. It is anticipated that TN levels should begin to decline over the next few years as the impact of removing septic nitrogen inputs begins to lower the nitrogen loading to this estuary.

Little Pond	TN 2005-2014			TN 2015-2017			MEP
Station	mean	s.d.	N	mean	s.d.	N	pre2004
Head	1.832	0.632	35	1.541	0.679	12	2.321
LP-1	1.314	0.542	73	1.309	0.447	21	0.942
LP-2	1.048	0.465	73	0.974	0.392	23	0.898
LP-3	0.918	0.363	71	0.802	0.274	24	0.745

Summary of Nutrient Related PondWatch Water Quality Data – Oyster Pond (2004-2014, 2015, 2016, 2017)

As is typical with other Falmouth embayments (Great, Green, and Bournes Pond) Oyster Pond (Figure 13) is separated from Vineyard Sound by a barrier beach and exchanges tidal waters through a single armored tidal inlet. However, unlike the other estuaries on the south shore of Falmouth, Oyster Pond has tidal flow control to maintain it as a brackish coastal pond. It also has a small saline lagoon between the inlet channel (Trunk River) and the pond, such that tidal flow enters the inlet and flows through the Trunk River, whose west branch flows to Oyster Pond through the shallow Lagoon. The beach and the opening to the lagoon are very dynamic geomorphic features due to the influence of littoral transport processes. Periodic sediment deposition, generally associated with storms, occludes the channel between the inlet and Lagoon which restricts the flow to Oyster Pond such that periodic dredging (bucket and drag line) is required to sustain the salt marshes within the Lagoon and the brackish nature of Oyster Pond.

Oyster Pond is situated such that managing it as a marine basin is not possible due to the distance from Vineyard Sound. Similarly, it is not possible to manage it as a fully freshwater pond, as there is periodic storm overwash bringing large volumes of salt water into Oyster Pond, therefore the best management option has been to manage the pond as a brackish water system, with salinities of the mixed surface layer between 2 and 4 ppt. This management option was determined from a multi-year assessment and options analysis conducted in the 1980's [1].

The weir installed between the Pond and Lagoon is set to maintain salinity in the preferred range by controlling tidal flooding. The weir requires that there be free flow between Vineyard Sound and the weir, such that the weir is the controlling structure. However, given the coastal processes, the channel between the lagoon and Trunk River becomes occluded with sand thereby reducing tidal flows, with the result that the pond water freshens over time. During fall/winter 2016 the channel became severely blocked and pond salinities declined to slightly less than 1.0 ppt, with negative impacts on phytoplankton communities (large blooms). PondWatch, in collaboration with the Town Department of Natural Resources, worked to resolve the blockage and salinity levels returned to ~2 ppt by summer. Presently, planning is underway to implement regular flow management. The salinity profiles show that the pond has generally been consistently brackish since the installation of the weir (previously salinity had risen to 24 ppt, with negative ecological consequences). Over the period 2004-2017, the pond water column completely mixed (vertically) on 2 occasions, 2008 and 2016, as can be seen in Figure 16. These events resulted in oxidation of bottom waters and loss of the very high inorganic nitrogen burden in the deep waters. It appears that Oyster Pond is gradually improving consistent with salinity management, with full restoration anticipated with the implementation of the Town's watershed nitrogen management actions, now being planned. Tracking of salinity is continuing as part of inlet management and nutrient related water quality monitoring will continue to assess the efficacy of planned watershed nitrogen management (nitrogen reducing septic systems or sewering or both).

It appears from the TN time-series (Figure 14, Table 5) that nitrogen levels in Oyster Pond may have increased from 2004-2014 to 2015-2017 in the upper mixed layer. However, given the periodic problems with maintaining tidal flows and the recent vertical mixing events, it is likely this is due to internal processes more than a significant increase in watershed nitrogen inputs.

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[1] The control structure has functioned as designed since its installation and continues to function based on current PondWatch data. This was one of the first management projects implemented for estuarine restoration by Falmouth and underpinned by PondWatch results and SMAST scientists with ACRE engineers.

Historically the deep waters of the main basin supported ~8 mg N/L due to prolonged anoxia. With the recent mixing, this stored nitrogen is moved into the surface waters which increases the TN level. This will eventually result in improved conditions, once the pond flushes out to Vineyard Sound. Overall, the TN concentration still exists within a relatively stable range of year to year variation of ~0.3 mg N/L and no distinct long-term trend at the sentinel station (OP-3) and also in the mid basin (OP-2) is apparent. The upper semi-enclosed basin yields highly variable results (particularly CHLA), likely due to its structure and direct surface water inflows and periodic blockage of tidal inflows. Whatever the cause, considering the 2015-2017 data, there is evidence that there has been a short-term change in the nutrient related water quality of the Oyster Pond Estuary in the mixed layer (slight increase) and deep layer (decrease; Figure 14, Figure 15, Table E and 5). As a point of reference, the MEP developed TN threshold for Oyster Pond is 0.633, 0.588 and 0.548 mg/L depending on target bottom water oxygen minima (D.O.: 3.8 mg/L, 5.0 mg/L, 6.0 mg/L, respectively) to support infaunal restoration.

As noted above, salinity of the mixed layer of the pond has varied, with a tendency to have higher TN levels at lower salinities, either due to reduced flushing or a shift in the importance of phosphorus as a control on phytoplankton growth. Salinity in Oyster Pond has been decreasing since 2013 and there has been a corresponding increase in TN levels over the same period due to decreased flushing (Figure 16). However, in 2017 it is clear salinity went up with a corresponding decrease in TN concentration (as would be expected with the introduction of lower TN concentration water from Vineyard Sound). As a result, monitoring of the inlet for blockages is being intensified. It is critical to note that the weir should not be adjusted as it is virtually certain that flow issues stem from periodic Trunk River flow restrictions, not the weir adjustment. The weir is designed to maintain salinity in the 2-4 ppt range, which it did for 7 of the 12 recent years. It is more acceptable to have the salinity rise slightly than to have it drop to 1 ppt as it did in 2009 and again in 2016. It should be stressed that the issue of low salinity in the pond can likely be solved by Trunk River channel management and needs to be encouraged. No general gradient of fresher inner to more marine outer basins has been observed because Oyster Pond salinity is controlled to maintain the system as a freshwater pond.

While Oyster Pond appears to have not become more impaired since the MEP assessment, it also shows little sign of improvement. Although the large mass of nitrogen held within the pond waters has declined, the levels of nitrogen continue to drive the impairment of pond water quality. While the chlorophyll-*a* levels are generally moderate (average <10ug/L) in the middle and lower part of the system, there are periodic large phytoplankton blooms, e.g. 2011-2012 and 2015-2017 (Figure 15) and clear increase in total pigment in 2017 at station OP-1 in the upper portion of the Pond (~20-65 ug/L in the mixed layer, Table E, 2015-2017). Most importantly, each of the Oyster Pond basins becomes oxygen depleted each summer and the deep basin (OP-3) continues to be mainly anoxic with sulfidic bottom waters. This is the major impediment to improving benthic animal habitat in this estuary and while the deeper basin is hypoxic/anoxic due to its physical structure, restoration of the other basins (OP-1, OP-2) is possible with proper nutrient management.

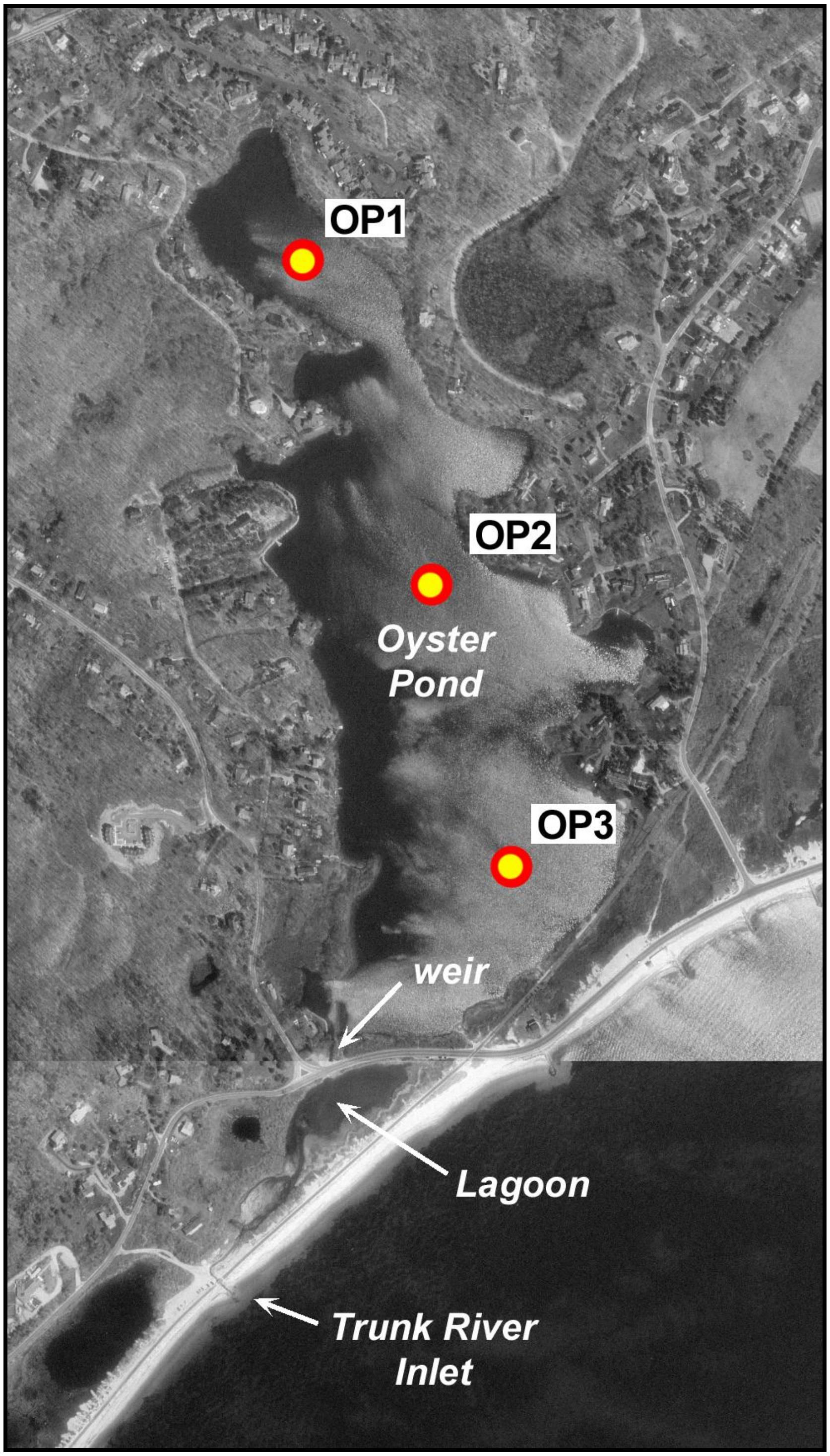
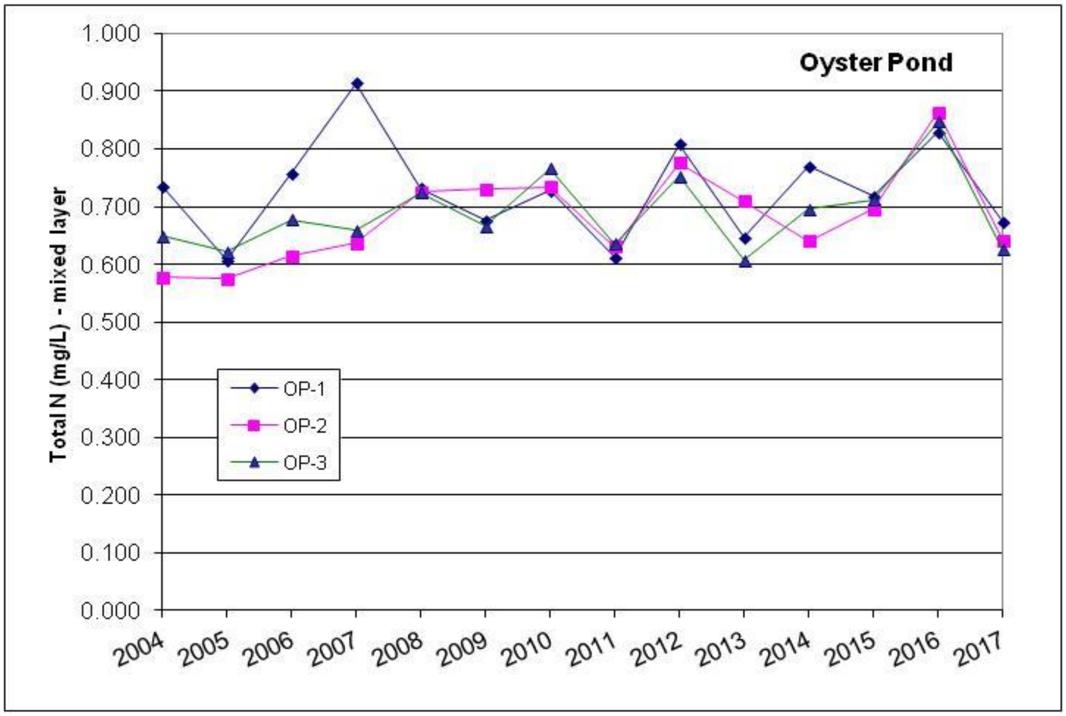


Figure 13 Oyster Pond water quality sampling stations for SMAST-PondWatch 2004-2017 and nutrient related water quality baseline used in the Massachusetts Estuaries Project analysis.



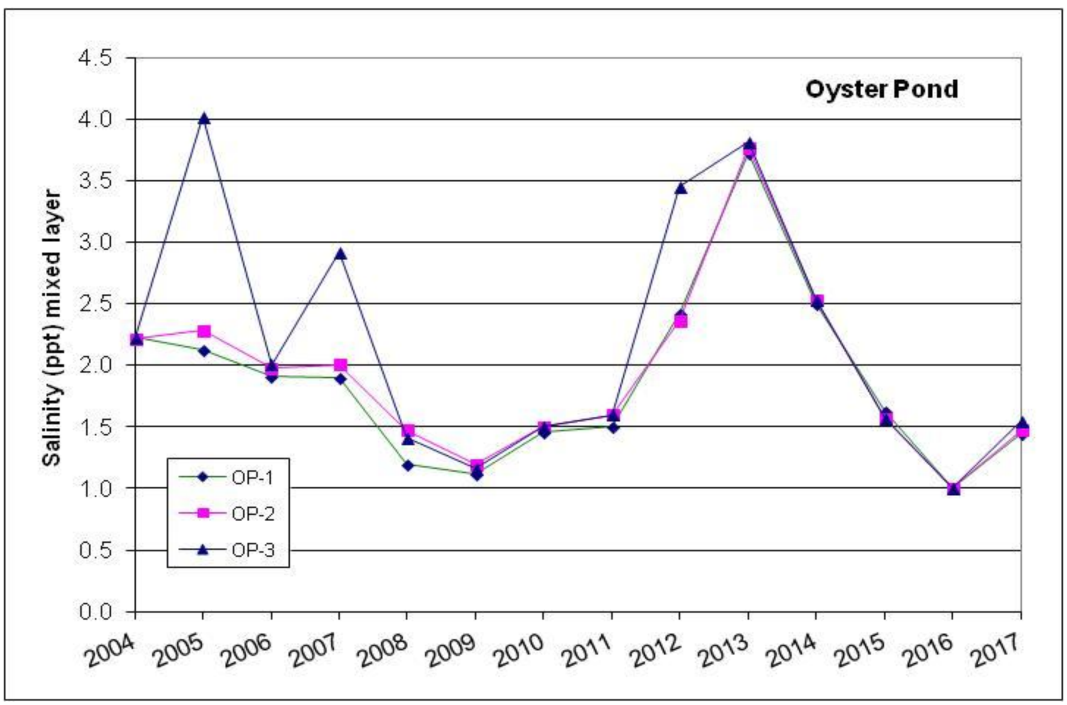


Figure 14. Annual averages for Oyster Pond nutrient related water quality post-MEP analysis 2004-2017 from SMAST-PondWatch for stations shown in Figure 13. Top: TN station averages at stations shown in Figure 13. Bottom: Salinity station averages.

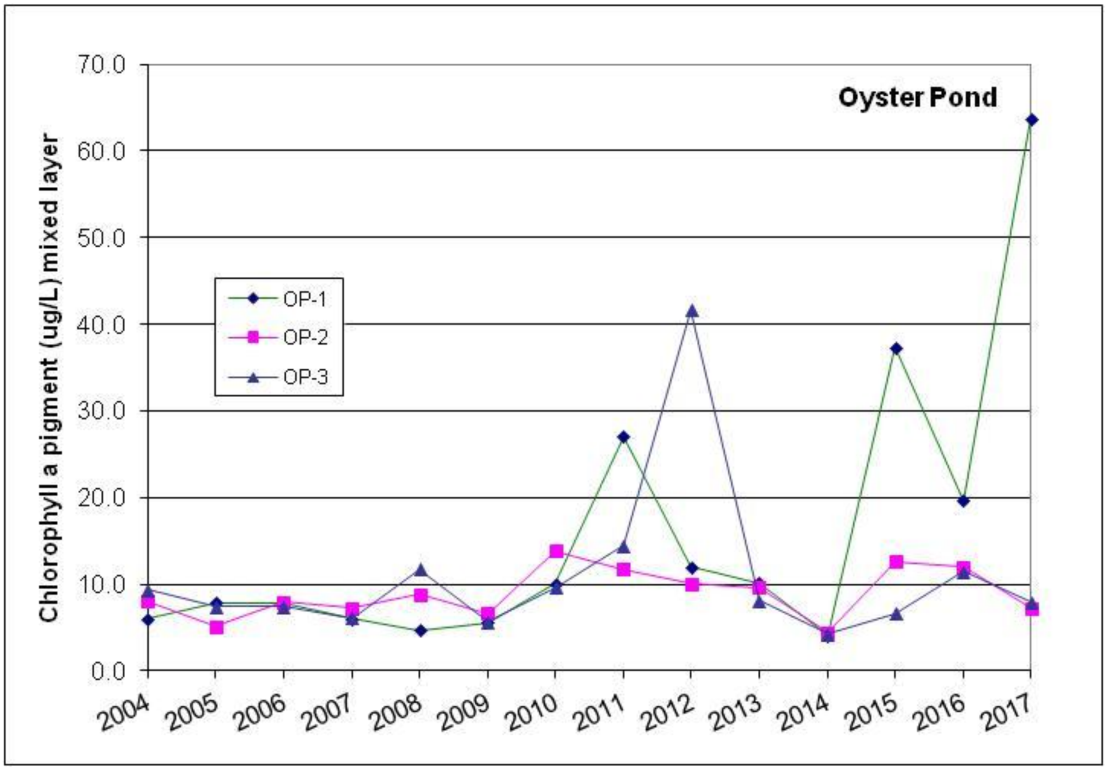


Figure 15. Annual averages (mixed layer) for Oyster Pond nutrient related water quality post-MEP analysis 2004-2017 from SMAST-PondWatch for stations shown in Figure 13. Total chlorophyll-*a* pigment as indicator of phytoplankton biomass. Averages >10 ug/L are indicative of nitrogen enrichment..

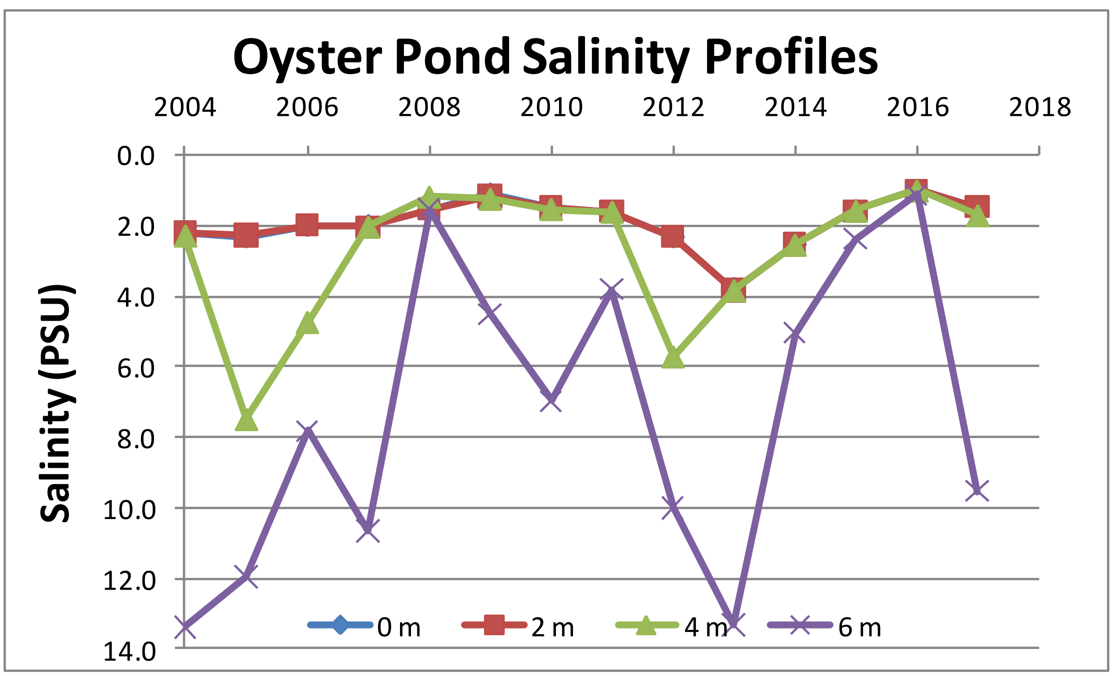


Figure 16. Oyster Pond Salinity profiles 2004-2017 at the deep station (OP-3). The pond has been salinity stratified each year except for 2008 and 2016, when the pond inlet was blocked and salt water inflows were highly restricted.

Table 5. Profiles of TN values (mg N/L) in Oyster Pond from 2004-2014, 2015-2017. Oyster Pond is typically density stratified with resulting anoxic bottom waters with high TN.

Oyster Pond		TN 2004-14			TN 2015-17		
Station	**Depth (m)**	**Mean**	**s.d.**	**N**	**Mean (m)**	**s.d.**	**N**
OP-1	**0**	0.683	0.109	39	0.751	0.206	12
OP-1	**2**	0.787	0.211	35	0.730	0.139	12
OP-1	**4**	2.654	1.190	39	1.971	1.193	12
OP-2	**0**	0.688	0.129	35	0.752	0.217	12
OP-2	**2**	0.638	0.116	36	0.706	0.196	12
OP-2	**3.25**	0.679	0.173	36	0.745	0.168	12
OP-3	**0**	0.724	0.120	36	0.757	0.206	13
OP-3	**2**	0.628	0.116	36	0.681	0.173	12
OP-3	**4**	0.680	0.119	35	0.747	0.153	11
OP-3	**6**	8.334	4.830	34	4.842	2.945	12

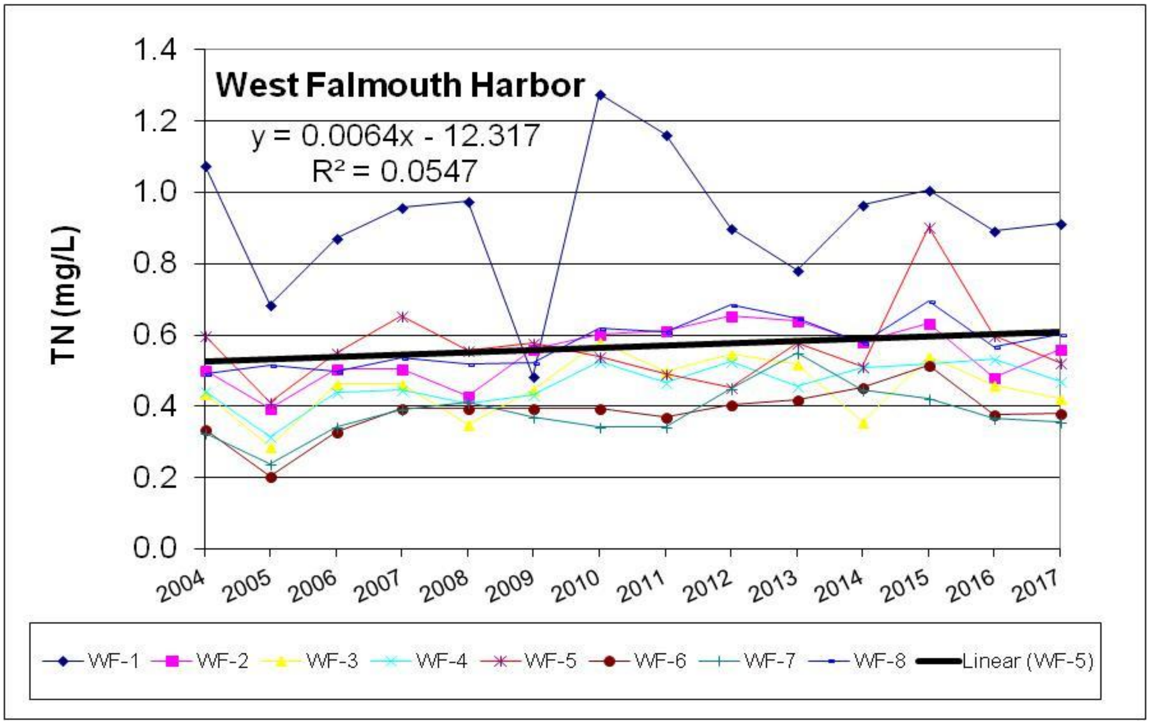
Summary of Nutrient Related PondWatch Water Quality Data – West Falmouth Harbor (2004-2012, 2013, 2014, 2015, 2016, 2017)

West Falmouth Harbor (Figure 17) exchanges tidal water with Buzzards Bay through a single armored inlet. PondWatch originally incorporated this Harbor system into its monitoring program to capture nitrogen increases and habitat changes associated with the new (at that time) nitrogen load originating from the new groundwater discharge of treated effluent from the West Falmouth Waste Water Treatment Facility (WWTF). This original WWTF has been upgraded with a lowering of nitrogen to the Harbor. The present monitoring effort is to document the changes in estuarine TN levels and associated habitat quality as the previous high nitrogen plume from the groundwater discharge from the old WWTF is replaced by the significantly lower nitrogen plume from the upgraded WWTF which went online in 2005. It was anticipated that based on the groundwater flow rate, the prior plume would have been partially flushed through by now, but it appears that residual nitrogen is still moving through the system (likely similar to the events with the decommissioning of the old MMA WWTF). Continued monitoring aims to capture these effects and the additional WWTF modifications that were completed in 2016 to improve the denitrification and sludge handling systems within the treatment plant. As in many cases the water quality monitoring data is the best determinant that the nitrogen reductions have reached the estuary.

It appears from the TN time-series (Figure 18, Table 6) that 2004-2014 and 2015-2017 nitrogen levels in portions of West Falmouth Harbor (WF-3,4,5,7) continue to trend upwards or are stable. The near stable conditions support the contention that the WWTF groundwater plume has not yet been "flushed out", with the consequence that nitrogen loading to the Harbor continues to increase slightly. The change in plume loading was not expected to be rapid as there is generally not a crisp delineation between the old plume's trailing edge and the new lower nitrogen plume's leading edge. More importantly, it has taken some time for the new WWTF to realize its nitrogen reduction due to logistics of plant operations. As such, nitrogen loads in the initial years were not lowered to the target level as quickly as planned. However, sentinel station WF-5 in Snug Harbor has been variable, with a large bloom at WF-5 in 2015 paralleling a spike in TN, which was not repeated in 2016 and 2017 where TN levels returned to the longer-term baseline. Given the variation in TN levels, it will likely take 3 years of monitoring after the old WWTF plume is "flushed out" to document a real improvement in water quality. At present it is not known if the low in 2017 is part of the natural variation or the first year of a new trend. It is therefore critical that monitoring continue in this sensitive system. As a point of reference, the MEP determined TN threshold at the sentinel station is 0.35 mg/L to support eelgrass restoration. Presently, the system remains above its TN threshold.

The changes in TN levels do not appear to be due to changes in tidal flushing as salinity continues to be relatively constant from year to year in the open water basins. Significantly, the chlorophyll-*a* levels, indicators of phytoplankton biomass/blooms, tend to mirror the TN levels, showing stable or declining levels where TN is stable or declining (Figure 19). However, there does appear to be some annual variability in this measure from 2014 to 2017. As such, it is important to continue to monitor this parameter. During the summer sampling season, it may also be useful to deploy in situ moorings in key areas such as the sentinel station to measure chlorophyll at a higher frequency for a longer duration, once it appears that conditions have changed. That will provide a clearer picture of the timing and intensity of phytoplankton biomass/blooms, a critical indicator of habitat impairment. While the TN to chlorophyll relationship exhibited in West Falmouth Harbor has been shown in numerous estuaries by the MEP, the relationship of TN to phytoplankton biomass shown here, increases confidence that management of nitrogen inputs will result in less blooms and clearer waters, as needed for eelgrass restoration.

Figure 17 West Falmouth Harbor water quality sampling stations for SMAST-PondWatch 2004-2017 and nutrient related water quality baseline used in the Massachusetts Estuaries Project analysis.



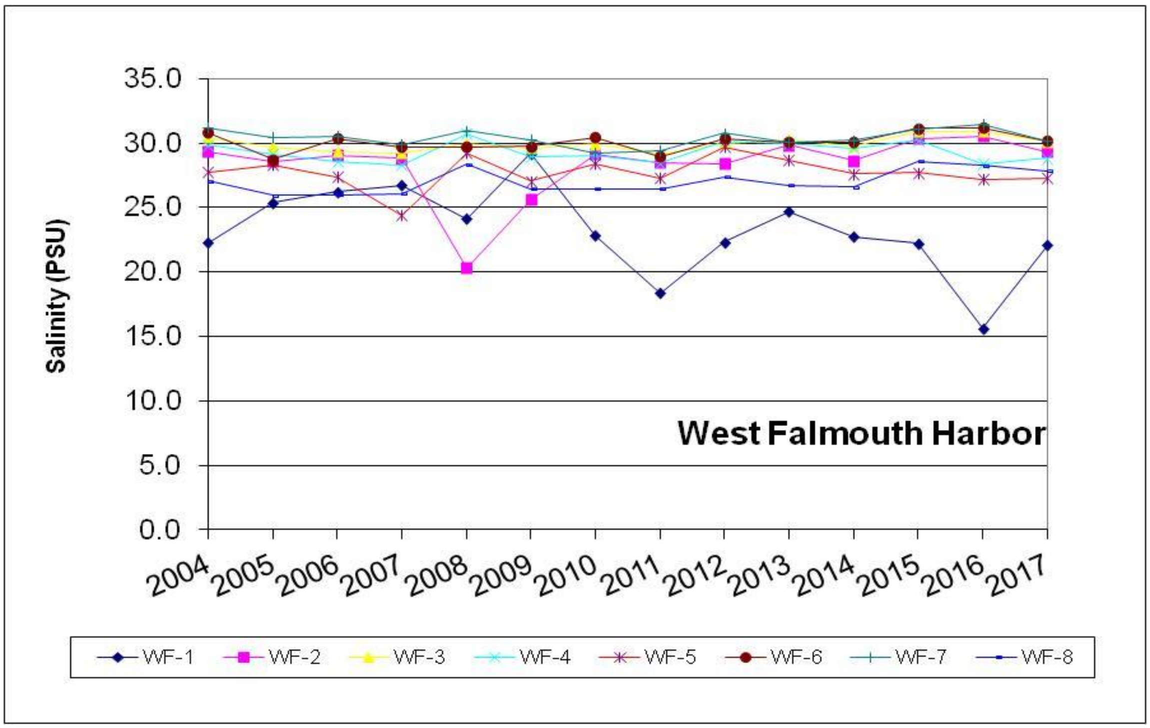


Figure 18. Annual averages for West Falmouth Harbor nutrient related water quality post-MEP analysis 2004-2017 from SMAST-PondWatch at stations shown in Figure 17. Top: Total Nitrogen station averages. Bottom: Salinity station averages. General gradient of fresher inner to more marine outer basins.

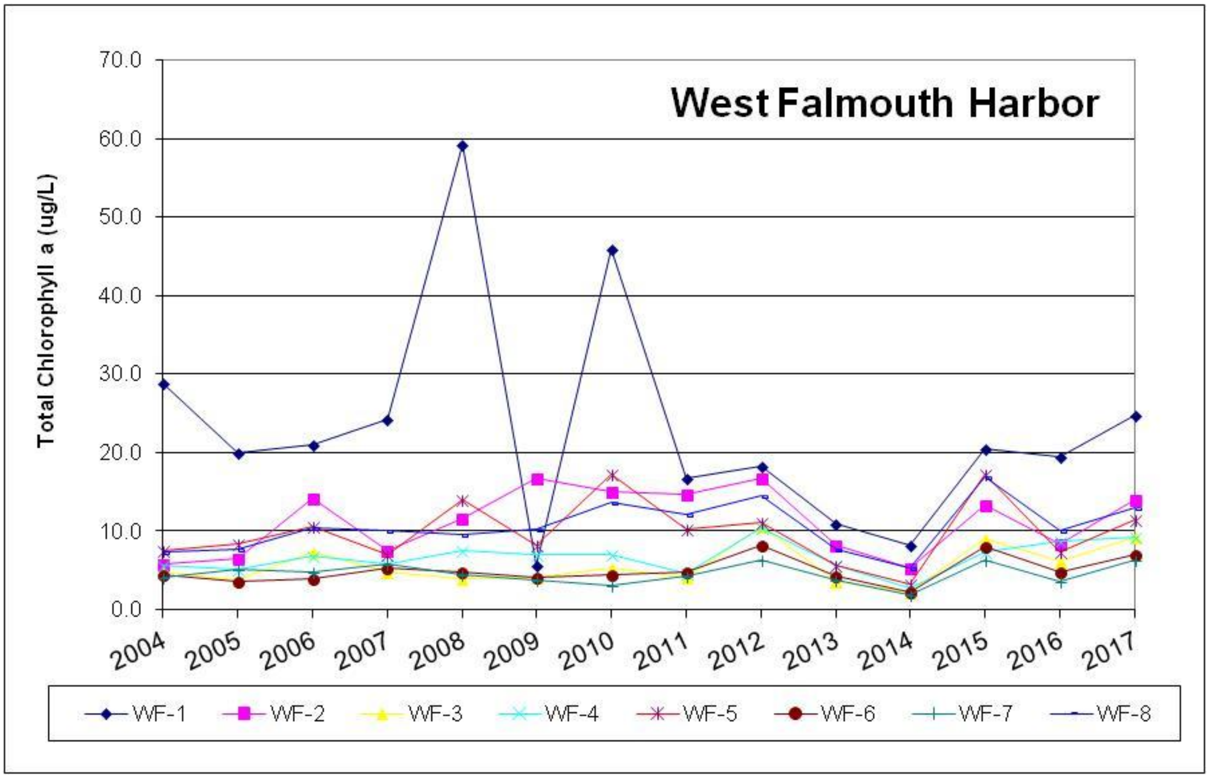


Figure 19. Annual averages for West Falmouth Harbor nutrient related water quality post-MEP analysis 2004-2017 from SMAST-PondWatch for stations shown in Figure 17. Total chlorophyll-*a* pigment as indicator of phytoplankton biomass. Averages >10 ug/L are indicative of nitrogen enrichment.

Table 6. TN values (mg N/L) in West Falmouth Harbor from 2004-2014, 2015-2017 and MEP averages pre-2004.

WF Hbr	TN 2004-2014 West Fal Hbr			TN 2015-2017 West Fal Hbr			MEP
Station	mean	s.d.	N	mean	s.d.	N	pre-2004
PWF1	0.890	0.337	65	0.936	0.258	29	0.742
PWF2	0.548	0.131	78	0.555	0.147	27	0.482
PWF3	0.444	0.115	80	0.477	0.128	32	0.415
PWF4	0.452	0.104	85	0.488	0.119	31	0.389
PWF5	0.531	0.117	79	0.561	0.184	51	0.444
PWF6	0.373	0.090	85	0.420	0.104	32	0.343
PWF7	0.366	0.085	83	0.384	0.098	32	0.346
PWF8	0.567	0.132	213	0.614	0.144	60	0.506

CONCLUSIONS

The past decade of SMAST-PondWatch water quality monitoring allows for some conclusions relative to the West Falmouth Harbor, Oyster Pond, Little Pond, Great Pond, Green Pond and Bournes Pond Estuaries within the Town of Falmouth.

A key concern for municipal managers relates to potential changes in water quality that may have occurred after completion of the Massachusetts Estuaries Project assessment. The water quality data collected in the period 2004-2017 generally indicates only small TN increase and more often, relatively consistent conditions with measurable interannual variation. This is not surprising since nitrogen management activities are in planning/permitting (e.g. Bournes Pond Bridge, Little Pond inlet, septic nitrogen reductions in Oyster Pond watershed) or that have been implemented relatively recently (e.g. West Falmouth WWTF upgrade, Little Pond sewer project) and have not yet impacted estuarine water quality due to lag times. These projects represent a significant effort by the Town of Falmouth to restore its estuaries and the results should begin to be seen from completed projects over the next few years and for the suite of actions over the next 5-10 years. The multi-year record described in detail above represents a major turn about in the Town's estuarine habitat quality, where there has been consistent or worsening habitat and water quality over the past decades.

More specifically:

1) All of the estuaries monitored by the Falmouth PondWatch Program have supported and continue to support nitrogen enriched waters with associated water and habitat quality impairments, particularly in their upper reaches. None of the systems have shown demonstrable improvement in water quality since the MEP assessments were completed. The general trend is for relatively consistent TN levels, with some basins showing possible small increases (2004-2017). It appears that without the planned nitrogen management actions, the Town of Falmouth can expect TN levels to increase as projected by the MEP and for habitat impairments to continue or to increase. However, it is important to note that there is no evidence of an imminent rapid decline in nitrogen related water quality, although conditions will gradually decline over time or stay consistently impaired until management actions are implemented.

2) Although improvements have been made to the West Falmouth Harbor WWTF to lower nitrogen loading to West Falmouth Harbor, it appears that the previously generated plume of nitrogen enriched groundwater from the prior treatement facility has not yet fully been "flushed" out of the aquifer. The result is that Mashapaquit Creek and adjacent Snug Harbor (WF-1 and WF-5, respectively) show TN levels over the past 8 years greater than 15% that found in the years preceeding 2004. It is significant that 4 of the 7 estuarine stations show increases greater than 10%. That said, Snug Harbor will certainly show declining TN levels as the new WWTF plume fully impacts the Harbor.

3) Resolving the restriction of tidal inflows to Little Pond due to sand occluding the undersized inlet is the final step in the restoration of Little Pond since the large investment in sewering the watershed. The impact of the sewer project (2017) has not yet been recognized in the water quality measurements as it will take a few years until the nitrogen stored in the groundwater system is flushed out. Based upon the watershed hydrology and comparison to other studies, significant estuarine restoration will occur gradually and continue over the next decade with the full improvement taking a bit longer (as is the case in West Falmouth Harbor). Upgrading the tidal inlet will accelerate the observable improvements in this system.

4) Bournes Pond shows a clear increase in TN at the Sentinel Station (B-3). Again, all stations in these latter 2 estuaries are showing small to moderate increases in TN over the past decade since the MEP analysis, consistent with their continued impaired habitat quality. The findings for both Little and Bournes Ponds are consistent with the gradual increase in nitrogen loading from continuing watershed development projected by the MEP as these watersheds approach build-out.

5) Falmouth PondWatch needs to undertake an evaluation of inlet maintenance relative to water quality within the associated estuaries as a means to economically lower the baseline TN levels, in concert with other nitrogen management alternatives being considered by the Town. Nitrogen management needs to consider tidal flushing in concert with watershed nitrogen management, particularly in Great Pond and possibly Green Pond, but especially relative to improving water quality in Little and Bournes Ponds.

Going forward it appears that continued monitoring in a consistent manner to provide comparable data over time is important to ensure that documentation of changes in baseline levels of key nutrient related metrics are captured, relative to management actions and meeting the USEPA/MassDEP TMDL. In addition, in West Falmouth Harbor, both lower loading from the WWTF resulting in declines in basin TN and gradual increases in watershed nitrogen inputs resulting in increases in TN in receiving waters needs to continue to be documented, as this estuary is on its way toward restoration of its nitrogen impaired habitats.

It appears that once again the role of the Falmouth PondWatch Program is changing to be part of adaptive management and compliance monitoring for these estuaries relative to their restoration. It appears that the baseline is sufficiently robust to be able to document the coming improvements in estuarine health that the Town of Falmouth and its citizen stewards have worked these many years to achieve.

ATTACHMENT 1

Compiled/Tabulated PondWatch Sampling Data for each Water Quality Parameter: Total Nitrogen, Salinity, Chlorophyll-*a* Data Collected Post-MEP

A. Bournes Pond (B)
(2004 – 2014, 2016)
Total Data Set Provided in Digital Format

B. Great Pond (Grt)
(2004 – 2014, 2016)
Total Data Set Provided in Digital Format

C. Green Pond (Grn)
(2004 – 2014, 2016)
Total Data Set Provided in Digital Format

D. Little Pond (LP)
(2005 – 2012, 2016)
Total Data Set Provided in Digital Format

E. Oyster Pond (OP)
(2004 – 2014, 2016)
Total Data Set Provided in Digital Format

F. West Falmouth Harbor (PWF)
(2004 – 2012, 2016)
Total Data Set Provided in Digital Format

Table A. Annual station averages for Bournes Pond SMAST-PondWatch sampling 2004-2017. Key metrics are presented as TN (total nitrogen), salinity and chlorophyll-*a* as an indicator of phytoplankton biomass. TN and chlorophyll-*a* levels indicate ecologically significant unabated nitrogen enrichment and is consistent with impaired nitrogen related habitat quality in the upper and mid Bournes Pond basins. Sentinel station is in yellow highlight. Full database provide electronically.

TN	**Bournes Pond**														**2004 - 2017**		
mg/L	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**mean**	**s.d.**	**N**
B1	0.865	0.906	0.918	1.013	1.009	1.294	0.994	0.907	1.244	1.259	1.297	1.326	1.103	1.321	1.085	0.254	54
B2	0.807	0.804	0.798	0.816	1.064	0.906	0.896	0.890	0.987	1.050	1.171	1.302	0.840	0.972	0.952	0.291	109
B3	**0.750**	**0.658**	**0.728**	**0.616**	**0.809**	**0.769**	**0.794**	**0.739**	**0.810**	**0.772**	**0.862**	**0.830**	**0.695**	**0.756**	**0.756**	**0.179**	**104**
B4	0.428	0.501	0.552	0.425	0.449	0.578	0.501	0.558	0.621	0.519	0.546	0.532	0.531	0.461	0.513	0.117	110
B5	0.629	0.748	0.766	0.650	0.680	0.627	0.807	0.690	0.725	0.644	0.718	0.577	0.571	0.529	0.670	0.144	110
B6	0.365	0.417	0.449	0.359	0.330	0.457	0.451	0.430	0.473	0.442	0.391	0.469	0.471	0.417	0.423	0.077	109

Salinity	**Bournes Pond**														**2004 - 2017**		
PSU	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**mean**	**s.d.**	**N**
B1	24.0	21.6	26.1	26.4	27.2	16.7	24.6	27.9	23.1	21.8	24.6	20.0	16.1	20.8	22.8	7.4	55
B2	27.8	25.7	27.2	27.6	27.1	26.2	27.7	26.4	27.3	23.4	26.6	27.2	27.8	24.6	26.6	4.2	110
B3	**27.5**	**27.7**	**27.9**	**28.1**	**26.5**	**28.2**	**28.7**	**27.6**	**28.7**	**27.3**	**27.8**	**28.3**	**29.0**	**27.5**	**27.9**	**1.9**	**108**
B4	31.4	28.6	29.2	30.1	28.1	29.1	30.1	29.3	30.4	29.4	30.3	30.9	30.1	30.1	29.8	1.3	109
B5	30.7	28.6	28.6	29.6	30.7	28.6	29.5	29.3	30.6	30.1	30.3	31.4	30.8	29.7	29.9	1.1	112
B6	30.6	29.3	29.3	30.3	29.1	28.8	30.5	29.9	30.4	29.3	30.8	31.1	30.7	30.6	30.0	1.2	110

T-pig	**Bournes Pond**														**2004 - 2017**		
ug/L	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**mean**	**s.d.**	**N**
B1	23.5	24.5	26.6	29.2	22.4	22.0	23.3	19.0	22.1	14.5	7.0	27.2	20.1	29.7	22.3	11.6	55
B2	18.8	21.0	19.8	18.4	41.7	20.3	14.4	11.7	13.6	10.4	9.5	19.7	18.9	14.9	18.2	14.0	109
B3	**16.2**	**11.9**	**23.3**	**9.7**	**18.5**	**20.6**	**11.3**	**8.8**	**10.5**	**7.9**	**3.3**	**13.3**	**12.4**	**17.8**	**13.3**	**10.9**	**107**
B4	7.2	11.1	14.8	5.0	6.8	10.6	6.9	8.0	8.4	6.0	2.5	6.8	11.9	6.1	8.0	5.0	111
B5	14.6	22.4	23.6	15.6	11.4	11.4	20.1	11.3	11.1	9.8	9.1	9.1	12.3	11.5	13.8	10.6	112
B6	5.7	10.2	8.3	4.4	3.8	11.5	4.8	5.2	7.7	5.3	2.1	5.1	6.4	5.3	6.1	4.4	110

Table B. Annual station averages for Great Pond SMAST-PondWatch sampling 2004-2017. Key metrics are presented as TN (total nitrogen), salinity and chlorophyll-*a* as an indicator of phytoplankton biomass. TN and chlorophyll-*a* levels indicate ecologically significant unabated nitrogen enrichment and is consistent with impaired nitrogen related habitat quality in Great Pond basins. Sentinel station is in yellow highlight. Full database provide electronically.

Total N (mg/L)			Falmouth PondWatch Program: Great Pond												2004 - 2017		
Station	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**Mean**	**s.d.**	**N**
Grt1	0.949	1.016	0.969	0.903	0.978	1.181	1.541	1.013	1.240	1.285	1.143	1.204	1.558	1.239	1.157	0.262	54
Grt2	1.130	1.055	1.049	0.938	1.146	0.999	1.102	1.130	1.302	1.146	0.855	1.263	0.992	1.153	1.088	0.244	110
Grt3	0.903	0.844	0.871	0.754	0.892	0.947	0.951	0.831	1.105	0.872	0.759	0.957	0.776	0.881	0.882	0.228	110
Grt4	0.959	0.999	1.085	0.898	1.163	1.016	1.141	1.071	1.141	1.197	0.903	0.974	0.975	0.979	1.027	0.265	109
Grt5	0.878	0.768	0.844	0.615	0.977	0.747	0.720	0.800	0.792	0.853	0.694	0.740	0.734	0.771	0.779	0.181	109
Grt6	0.557	0.577	0.598	0.611	0.664	0.576	0.612	0.638	0.889	0.626	0.464	0.687	0.625	0.612	0.624	0.159	109

Salinity (ppt)			Falmouth PondWatch Program: Great Pond												2004 - 2017		
Station	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**Mean**	**s.d.**	**N**
Grt1	0.5	0.2	0.1	0.8	30.9	7.7	6.5	0.4	7.0	1.1	8.7	2.0	1.0	2.2	5.329	10.153	54
Grt2	24.0	19.4	16.8	20.3	14.3	20.2	18.7	17.3	19.6	19.3	19.9	18.9	20.4	17.9	18.985	10.072	110
Grt3	26.8	25.4	21.2	24.0	15.5	23.6	21.2	23.1	24.0	25.5	25.3	24.4	26.2	24.6	23.589	7.826	110
Grt4	26.0	24.2	22.2	24.3	25.4	22.8	24.1	21.1	24.3	22.7	24.5	25.6	26.3	24.0	24.123	3.763	109
Grt5	25.9	26.9	23.7	28.4	19.4	25.8	25.8	24.6	28.2	25.9	27.5	27.9	28.8	27.1	26.116	4.691	109
Grt6	28.2	27.6	25.5	28.2	24.8	28.3	28.9	27.6	28.0	28.1	28.0	28.9	29.0	28.7	27.833	3.189	109

Total Pigments (ug/L)			Falmouth PondWatch Program: Great Pond												2004 - 2017		
Station	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**Mean**	**s.d.**	**N**
Grt1	12.1	7.5	6.6	5.1	8.3	7.4	21.7	7.2	9.6	4.1	4.5	8.3	10.7	13.2	9.029	9.741	54
Grt2	31.1	29.6	19.7	17.3	29.5	23.6	24.9	32.1	21.8	13.8	5.7	18.0	20.7	18.9	21.857	14.257	110
Grt3	13.0	28.9	23.5	12.8	32.5	20.9	16.4	20.2	17.1	13.0	6.7	17.1	18.3	18.6	18.502	10.900	110
Grt4	21.2	30.1	25.0	15.0	43.5	25.9	23.7	25.2	24.3	14.8	9.9	18.4	24.9	20.1	22.964	11.706	109
Grt5	24.8	21.0	22.7	12.5	34.3	20.1	16.4	22.1	13.3	7.9	7.0	10.2	13.5	16.6	17.315	14.892	109
Grt6	7.6	11.2	10.7	5.7	15.8	14.0	9.8	12.2	11.4	6.5	3.9	7.3	9.2	11.7	9.784	5.124	109

Table C. Annual station averages for Green Pond SMAST-PondWatch sampling 2004-2017. Key metrics are presented as TN (total nitrogen), salinity and chlorophyll-*a* as an indicator of phytoplankton biomass. TN and chlorophyll-*a* levels indicate ecologically significant unabated nitrogen enrichment and is consistent with impaired nitrogen related habitat quality in the upper and mid Green Pond basins. Sentinel station is in yellow highlight. Full database provide electronically.

Total N (mg/L)				Falmouth PondWatch Program: Green Pond											2004 - 2017	
Station	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Mean	s.d.	N
GP1	1.759	1.267	1.213	1.613	1.505	1.554	1.233	1.191	1.121	0.990	1.210	1.339	1.388	1.330	1.321	0.348	55
GP2	1.081	1.210	1.342	1.179	1.268	1.282	1.122	1.102	1.243	1.245	0.828	1.049	1.027	1.208	1.110	0.248	105
GP2A	0.915	0.996	1.004	0.880	0.989	1.055	1.158	0.974	1.074	1.014	0.795	1.087	1.103	0.921	0.985	0.209	108
GP3	0.782	0.776	0.749	0.828	0.812	0.764	0.918	0.908	0.947	0.920	0.768	0.893	0.712	0.825	0.828	0.186	108
GP4	0.586	0.579	0.637	0.677	0.607	0.637	0.761	0.624	0.722	0.688	0.617	0.638	0.688	0.627	0.634	0.139	109
GP5	0.465	0.488	0.446	0.421	0.394	0.542	0.555	0.493	0.583	0.494	0.361	0.528	0.561	0.480	0.476	0.103	128

Salinity (ppt)				Falmouth PondWatch Program: Green Pond											2004 - 2017	
Station	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Mean	s.d.	N
GP1	17.9	0.5	0.6	11.2	28.3	0.8	2.6	1.2	5.9	1.6	19.2	15.1	16.0	14.0	9.6	10.8	55
GP2	26.9	22.3	24.7	24.5	26.2	23.2	25.2	18.9	25.3	22.6	23.7	23.8	25.1	24.1	24.1	6.3	111
GP2A	27.2	22.2	22.3	26.5	24.5	23.9	26.3	20.4	24.9	23.6	25.6	25.2	26.1	25.8	24.7	5.5	107
GP3	27.0	25.8	23.7	26.6	26.3	26.8	24.8	22.2	26.4	24.6	25.9	27.2	26.9	26.2	25.8	4.1	110
GP4	28.5	27.5	24.0	27.5	26.6	27.8	27.3	27.1	28.5	26.4	28.4	28.0	28.2	28.5	27.4	3.7	112
GP5	30.1	28.8	29.1	29.5	28.8	29.0	29.8	29.1	29.7	29.2	29.9	30.5	30.0	29.6	29.5	1.5	134

Total Pigments (ug/L)				Falmouth PondWatch Program: Green Pond											2004 - 2017	
Station	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Mean	s.d.	N
GP1	46.8	29.9	19.5	29.1	19.1	8.5	17.1	8.9	23.8	14.2	8.5	19.8	26.7	38.4	22.4	21.4	55
GP2	32.3	39.2	17.7	28.6	36.1	36.9	38.7	21.9	22.6	17.2	6.1	19.5	23.7	21.2	25.9	15.6	111
GP2A	28.8	33.0	20.5	29.6	26.3	33.7	39.6	21.9	24.0	15.6	7.3	25.3	31.3	18.2	25.3	14.3	108
GP3	24.4	23.8	14.5	30.6	20.4	21.4	26.5	21.1	20.8	16.2	7.1	15.9	20.6	14.6	19.8	10.8	110
GP4	14.9	16.7	12.1	19.0	14.6	19.4	18.0	9.7	12.2	10.8	4.2	8.9	14.1	12.5	13.3	6.9	112
GP5	9.8	10.1	9.2	7.3	6.9	14.6	9.3	6.7	9.8	5.7	2.8	6.5	11.4	8.0	8.5	4.4	134

Table D. Annual station averages for Little Pond SMAST-PondWatch sampling 2005-2017. Key metrics are presented as TN (total nitrogen), salinity and chlorophyll-*a* as an indicator of phytoplankton biomass. TN and chlorophyll-*a* levels indicate ecologically significant unabated nitrogen enrichment and is consistent with impaired nitrogen related habitat quality in Little Pond basins. Sentinel station is in yellow highlight. Full database provide electronically.

TN (mg/L)			Falmouth PondWatch Program: Little Pond											2005 - 2017)		
Station	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Mean	s.d.	N
Head	1.534	1.725	1.791	2.016	2.217	1.717	2.200	1.525	1.983	1.611	1.590	1.688	1.346	1.758	0.650	47
LP-1	0.962	1.003	0.951	1.252	1.735	1.351	1.440	1.200	2.035	1.372	1.484	1.355	1.043	1.351	0.641	95
LP-2	0.900	0.768	0.916	0.951	1.126	0.974	1.062	0.894	2.085	1.049	1.251	0.890	0.752	1.030	0.447	96
LP-3	0.683	0.749	0.731	0.843	0.955	1.003	1.025	0.792	1.471	1.211	1.008	0.799	0.599	0.889	0.345	95
Salinity (PSU)			Falmouth PondWatch Program: Little Pond											2005 - 2017)		
Station	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Mean	s.d.	N
Head	21.0	25.1	24.1	25.7	6.3	20.5	16.7	20.9	18.2	24.8	22.8	22.9	26.5	20.6	9.1	49
LP-1	27.1	27.7	27.8	28.5	19.0	23.8	22.7	25.9	26.1	25.6	23.1	25.8	27.0	25.1	6.5	98
LP-2	27.3	28.1	27.7	25.2	24.5	26.9	25.7	27.3	27.0	26.3	28.1	29.5	28.5	27.0	3.6	97
LP-3	27.5	27.7	29.4	26.9	26.5	27.4	26.3	28.9	26.8	26.0	28.7	29.5	27.9	27.8	2.8	95
T-pigment (ug/L)			Falmouth PondWatch Program: Little Pond											2005 - 2017)		
Station	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Mean	s.d.	N
Head	35.8	38.9	44.3	42.3	23.9	18.9	11.9	25.6	8.4	2.6	17.4	17.2	20.2	24.6	21.0	48
LP-1	23.5	16.3	29.6	34.3	14.0	27.6	13.9	24.1	15.4	3.0	16.6	22.4	17.1	20.7	16.7	98
LP-2	22.3	14.1	17.2	20.9	19.3	13.4	14.7	22.1	24.1	2.3	7.2	19.8	12.4	16.5	13.8	97
LP-3	10.1	10.4	9.9	15.2	27.1	48.3	9.1	19.1	9.2	2.3	5.6	14.0	9.1	15.4	28.0	94

Table E. Annual station averages for Oyster Pond SMAST-PondWatch sampling 2004-2017. Key metrics are presented as TN (total nitrogen), salinity and chlorophyll-*a* as an indicator of phytoplankton biomass. TN and chlorophyll-*a* levels indicate ecologically significant unabated nitrogen enrichment and is consistent with impaired nitrogen related habitat quality, particularly benthic infauna. Full database provideD electronically.

Total N (mg/L)		Falmouth PondWatch Program: Oyster Pond														2004 - 2017		
Station	**Depth (m)**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**Mean**	**s.d.**	**N**
OP-1	**0**	0.745	0.530	0.683	0.705	0.667	0.646	0.725	0.622	0.767	0.648	0.767	0.695	0.878	0.679	0.699	0.138	51
OP-1	**2**	0.721	0.685	0.833	1.194	0.817	0.723	0.730	0.602	0.849	0.647	0.773	0.742	0.780	0.668	0.772	0.196	47
OP-1	**4**	1.674	1.509	3.649	2.638	2.550	4.109	3.256	2.867	2.737	2.624	1.924	1.451	1.149	3.315	2.494	1.215	51
OP-2	**0**	0.617	0.498	0.659	0.758	0.692	0.832	0.738	na	0.791	0.640	0.677	0.711	0.906	0.640	0.704	0.156	47
OP-2	**2**	0.548	0.589	0.597	0.570	0.635	0.628	0.703	0.687	0.790	0.692	0.614	0.686	0.829	0.603	0.655	0.141	48
OP-2	**3.25**	0.567	0.620	0.588	0.583	0.843	0.731	0.762	0.575	0.746	0.827	0.622	0.692	0.858	0.684	0.696	0.172	48
OP-3	**0**	0.733	0.642	0.716	0.736	0.789	0.734	0.818	0.609	0.763	0.620	0.757	0.777	0.860	0.607	0.733	0.146	49
OP-3	**2**	0.648	0.548	0.622	0.568	0.671	0.605	0.675	0.602	0.697	0.579	0.701	0.649	0.789	0.604	0.641	0.133	48
OP-3	**4**	0.587	0.676	0.692	0.673	0.714	0.660	0.776	0.696	0.846	0.622	0.632	0.711	0.905	0.666	0.696	0.130	46
OP-3	**6**	15.257	8.401	10.503	10.880	5.198	5.495	6.748	2.487	6.666	14.237	1.022	3.833	2.991	7.702	7.423	4.651	46
mixed layer		**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**Mean**	**s.d.**	**N**
OP-1	**0-2**	0.735	0.607	0.758	0.915	0.732	0.677	0.728	0.612	0.808	0.647	0.771	0.719	0.829	0.674	0.734	0.171	98
OP-2	**0-3.25**	0.578	0.575	0.615	0.637	0.726	0.730	0.735	0.631	0.776	0.710	0.641	0.696	0.864	0.642	0.685	0.157	143
OP-3	**0-4**	0.649	0.622	0.677	0.659	0.725	0.666	0.767	0.636	0.753	0.607	0.697	0.712	0.848	0.626	0.690	0.141	143

Total Pigments (ug/L)		Falmouth PondWatch Program: Oyster Pond														2004 - 2017		
Station	**Depth (m)**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**Mean**	**s.d.**	**N**
OP-1	**0**	6.4	11.2	7.3	5.6	3.9	5.7	7.2	8.0	8.2	7.6	3.3	5.5	10.6	9.6	7.2	5.5	52.0
OP-1	**2**	5.8	4.5	8.3	6.5	5.4	5.4	13.0	46.1	15.8	12.7	4.6	9.2	12.0	9.6	9.6	8.2	52.0
OP-1	**4**	130.0	57.0	125.8	82.6	159.4	256.1	44.2	181.8	53.1	53.2	27.0	97.5	57.5	172.2	105.2	87.5	51.0
OP-2	**0**	4.6	3.6	7.8	6.2	6.2	6.7	9.2	na	7.4	6.9	4.5	24.5	12.2	7.1	8.4	10.4	51.0
OP-2	**2**	5.2	4.0	7.9	7.0	7.7	5.9	13.2	12.6	10.9	8.4	4.4	7.6	11.4	6.5	7.9	5.2	51.0
OP-2	**3.25**	14.3	7.7	8.1	8.6	12.6	7.4	19.2	10.9	12.0	14.9	4.4	5.9	12.6	8.4	10.5	6.8	51.0
OP-3	**0**	4.8	2.8	6.4	4.8	5.2	2.8	7.9	11.2	8.7	6.3	4.1	5.6	9.8	6.3	6.1	4.1	52.0
OP-3	**2**	8.5	3.3	6.7	4.3	4.9	6.3	8.2	12.2	10.0	8.0	4.0	5.7	10.3	6.5	6.8	4.4	51.0
OP-3	**4**	14.8	16.1	9.2	9.3	25.2	7.9	12.8	20.2	106.2	10.1	4.8	8.8	16.1	11.1	20.0	31.8	50.0
OP-3	**6**	134.2	158.0	47.4	82.4	37.2	25.7	102.4	91.8	46.5	49.4	13.0	82.6	44.2	72.9	69.9	53.6	48.0
mixed layer		**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**Mean**	**s.d.**	**N**
OP-1	**0-4**	6.1	7.8	7.8	6.0	4.7	5.6	10.1	27.0	12.0	10.1	4.1	37.4	19.6	63.8	40.2	67.8	0.8
OP-2	**0-3.25**	8.0	5.1	7.9	7.3	8.8	6.7	13.9	11.8	10.1	9.6	4.4	12.6	12.0	7.3	8.9	7.8	0.7
OP-3	**0-4**	9.4	7.4	7.4	6.1	11.8	5.7	9.6	14.5	41.6	8.2	4.3	6.7	11.5	8.0	10.9	19.5	1.6

Salinity (ppt)		Falmouth PondWatch Program: Oyster Pond														2004 - 2017		
Station	**Depth (m)**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**Mean**	**s.d.**	**N**
OP-1	**0**	2.1	2.1	1.9	1.9	1.5	1.1	1.5	1.5	2.6	3.7	2.5	1.6	1.0	1.5	1.9	0.7	52
OP-1	**2**	2.4	2.1	1.9	1.9	2.3	1.1	1.5	1.5	2.3	3.8	2.5	1.7	1.0	1.4	2.0	1.0	51
OP-1	**4**	2.0	2.1	2.1	1.8	1.5	1.0	1.4	1.4	2.0	3.8	2.4	1.5	0.9	1.3	1.8	0.7	52
OP-2	**0**	2.2	2.2	2.0	2.0	1.5	1.2	1.5	na	2.3	3.8	2.5	1.6	1.0	1.5	1.9	0.7	51
OP-2	**2**	2.2	2.3	2.0	2.1	1.4	1.2	1.5	1.6	2.4	3.8	2.5	1.6	1.0	1.5	1.9	0.7	51
OP-2	**3.25**	2.2	2.4	2.0	2.0	1.5	1.2	1.5	1.6	2.4	3.7	2.5	1.6	1.0	1.5	2.0	0.7	51
OP-3	**0**	2.2	2.3	2.0	2.0	1.5	1.1	1.5	1.6	2.3	3.8	2.5	1.6	1.0	1.5	1.9	0.7	52
OP-3	**2**	2.2	2.3	2.0	4.7	1.5	1.2	1.5	1.6	2.3	3.8	2.5	1.6	1.0	1.5	2.2	1.7	51
OP-3	**4**	2.3	7.5	2.0	2.0	1.2	1.2	1.5	1.6	5.7	3.8	2.5	1.6	1.0	1.7	2.7	2.0	50
OP-3	**6**	13.4	12.0	7.8	10.7	1.5	4.5	7.0	3.8	10.0	13.3	5.0	2.4	1.1	9.5	7.6	5.1	51
mixed layer		**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**Mean**	**s.d.**	**N**
OP-1	**0-2**	2.2	2.1	1.9	1.9	1.9	1.1	1.5	1.5	2.4	3.7	2.5	1.6	1.0	1.5	1.9	0.9	103
OP-2	**0-3.25**	2.2	2.3	2.0	2.0	1.5	1.2	1.5	1.6	2.4	3.8	2.5	1.6	1.0	1.5	2.0	0.7	153
OP-3	**0-4**	2.2	4.0	2.0	2.9	1.4	1.2	1.5	1.6	3.5	3.8	2.5	1.6	1.0	1.6	2.2	1.6	153

Table F. Annual station averages for West Falmouth Harbor SMAST-PondWatch sampling 2004-2017. Key metrics are presented as TN (total nitrogen), salinity and chlorophyll-*a* as an indicator of phytoplankton biomass. TN and chlorophyll-*a* levels indicate ecologically significant unabated nitrogen enrichment particularly in the inner reaches and is consistent with impaired nitrogen related habitat quality, particularly eelgrass in the inner basins. Sentinel station is in yellow highlight. Full database provide electronically.

TN (mg/L)			Falmouth PondWatch Program: West Falmouth Harbor												2004 - 2017		
Station	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	mean	s.d.	N
PWF1	1.078	0.686	0.872	0.959	0.977	0.486	1.277	1.162	0.899	0.782	0.966	1.006	0.893	0.904	0.892	0.318	97
PWF2	0.501	0.394	0.506	0.505	0.430	0.562	0.603	0.613	0.653	0.640	0.582	0.635	0.480	0.534	0.542	0.138	109
PWF3	0.437	0.286	0.466	0.465	0.348	0.446	0.581	0.499	0.548	0.457	0.357	0.542	0.461	0.422	0.447	0.123	116
PWF4	0.443	0.315	0.441	0.446	0.408	0.434	0.526	0.467	0.528	0.456	0.509	0.488	0.515	0.469	0.455	0.113	120
PWF5	0.599	0.410	0.551	0.653	0.556	0.578	0.538	0.492	0.455	0.543	0.511	0.555	0.598	0.522	0.553	0.153	136
PWF6	0.336	0.205	0.329	0.396	0.395	0.394	0.395	0.372	0.406	0.418	0.454	0.487	0.377	0.381	0.383	0.096	121
PWF7	0.324	0.238	0.345	0.391	0.411	0.371	0.342	0.344	0.451	0.446	0.394	0.421	0.368	0.358	0.367	0.090	119
PWF8	0.493	0.514	0.497	0.537	0.521	0.522	0.618	0.610	0.684	0.649	0.579	0.672	0.568	0.603	0.572	0.138	282

Salinity (PSU)			Falmouth PondWatch Program: West Falmouth Harbor												2004 - 2017		
Station	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	mean	s.d.	N
PWF1	22.3	25.4	26.2	26.7	24.1	29.2	22.8	18.3	22.3	24.7	22.7	22.2	15.6	22.1	23.1	6.0	102
PWF2	29.3	28.6	29.1	28.8	20.3	25.6	29.1	28.5	28.4	29.8	28.6	30.3	30.6	29.3	28.4	3.4	116
PWF3	30.4	29.7	29.3	29.2	30.0	29.6	29.9	29.1	30.0	30.2	29.8	30.9	30.9	30.1	30.0	1.0	117
PWF4	29.8	29.2	28.6	28.3	30.7	29.0	29.1	28.4	30.2	30.0	29.6	30.2	28.4	28.8	29.3	1.5	124
PWF5	27.7	28.3	27.4	24.4	29.3	27.0	28.4	27.3	29.7	28.7	27.6	27.7	27.2	27.3	27.7	2.7	144
PWF6	30.8	28.7	30.4	29.7	29.7	29.7	30.4	28.9	30.4	30.1	30.1	31.1	31.2	30.1	30.2	1.3	122
PWF7	31.2	30.5	30.6	29.9	30.9	30.3	29.2	29.4	30.8	30.1	30.2	31.1	31.4	30.2	30.4	1.1	121
PWF8	27.1	25.9	26.0	26.1	28.4	26.5	26.5	26.4	27.4	26.7	26.6	28.6	28.2	27.9	27.0	2.1	284

Total Pigment (ug/L)			Falmouth PondWatch Program: West Falmouth Harbor												2004 - 2017		
Station	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	mean	s.d.	N
PWF1	28.8	20.0	21.0	24.2	59.3	5.6	46.0	16.6	18.3	10.9	8.2	20.5	19.5	24.8	25.0	26.5	101
PWF2	5.8	6.5	14.2	7.4	11.5	16.8	15.0	14.7	16.7	8.1	5.3	13.3	8.4	14.0	11.3	8.0	115
PWF3	4.8	3.8	7.3	4.8	4.0	4.2	5.3	4.1	10.7	3.6	2.2	9.1	6.2	9.3	5.8	3.8	117
PWF4	5.7	5.0	6.8	5.8	7.4	6.9	6.9	4.6	10.5	5.6	2.7	7.3	8.8	9.2	6.6	3.8	124
PWF5	7.5	8.3	10.5	7.0	14.0	8.1	17.2	10.2	11.1	5.6	3.2	17.2	7.3	11.4	10.4	7.5	141
PWF6	4.5	3.6	3.9	5.2	4.8	4.1	4.4	4.7	8.2	4.2	2.3	8.0	4.8	7.0	5.0	2.7	122
PWF7	4.1	5.1	4.8	5.8	4.4	3.8	3.0	4.3	6.2	3.8	1.9	6.2	3.6	6.3	4.5	2.6	122
PWF8	7.4	7.6	10.4	10.1	9.6	10.3	13.7	12.2	14.4	7.6	5.2	16.9	10.0	13.0	10.4	6.2	284

ATTACHMENT 2

PondWatch Station Location (coordinates)

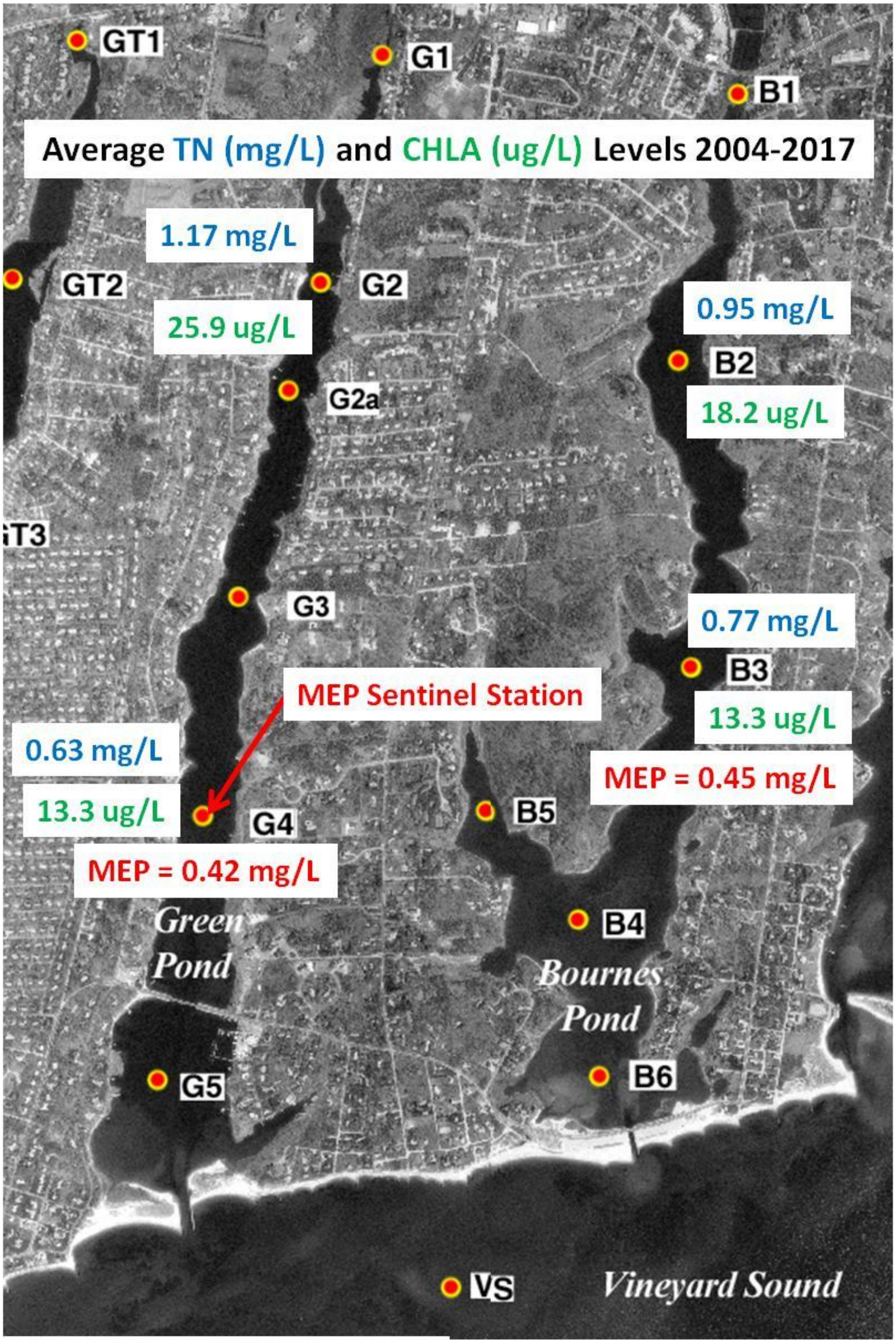
Estuary	Station	Lat		Lon	
Bournes Pond	BP1	41	34.5473	70	33.1064
	BP2	41	34.3255	70	33.1394
	BP3	41	33.7118	70	33.2026
	BP4	41	33.3261	70	33.4195
	BP5	41	33.443	70	33.6227
Great Pond	GTP1	41	34.6531	70	34.4303
	GTP2	41	34.2902	70	34.5759
	GTP3	41	33.8942	70	34.7187
	GTP4	41	33.9875	70	35.0868
	GTP5	41	33.6433	70	34.9631
	GTP6	41	33.0918	70	34.9358
Green Pond	GP1	41	34.5929	70	33.8342
	GP2	41	34.3068	70	33.9414
	GP2A	41	34.9389	70	34.0018
	GP3	41	33.8092	70	34.1282
	GP4	41	33.3842	70	34.2079
	GP5	41	33.0545	70	34.2546
Little Pond	LPHEAD	41	33.4576	70	35.4993
	LP1	41	33.4078	70	35.4925
	LP2	41	33.1797	70	35.4101
	LP3	41	32.9071	70	35.3579
Oyster Pond	OPHEAD	41	32.7424	70	38.5021
	OP1	41	32.7341	70	38.414
	OP2	41	32.5029	70	38.3191
	OP3	41	32.3629	70	38.2476
West Falmouth Harbor	WFH1	41	36.528	70	38.2314
	WFH2	41	35.8842	70	38.5383
	WFH3	41	35.9785	70	38.6815
	WFH4	41	36.2533	70	38.4792
	WFH5	41	36.4078	70	38.4076
	WFH6	41	36.4029	70	38.6285
	WFH7	41	36.3766	70	38.9981
	WFH8	41	35.7079	70	38.2383
Vineyard Sound	VS1	41	32.6798	70	34.2327

ATTACHMENT 3

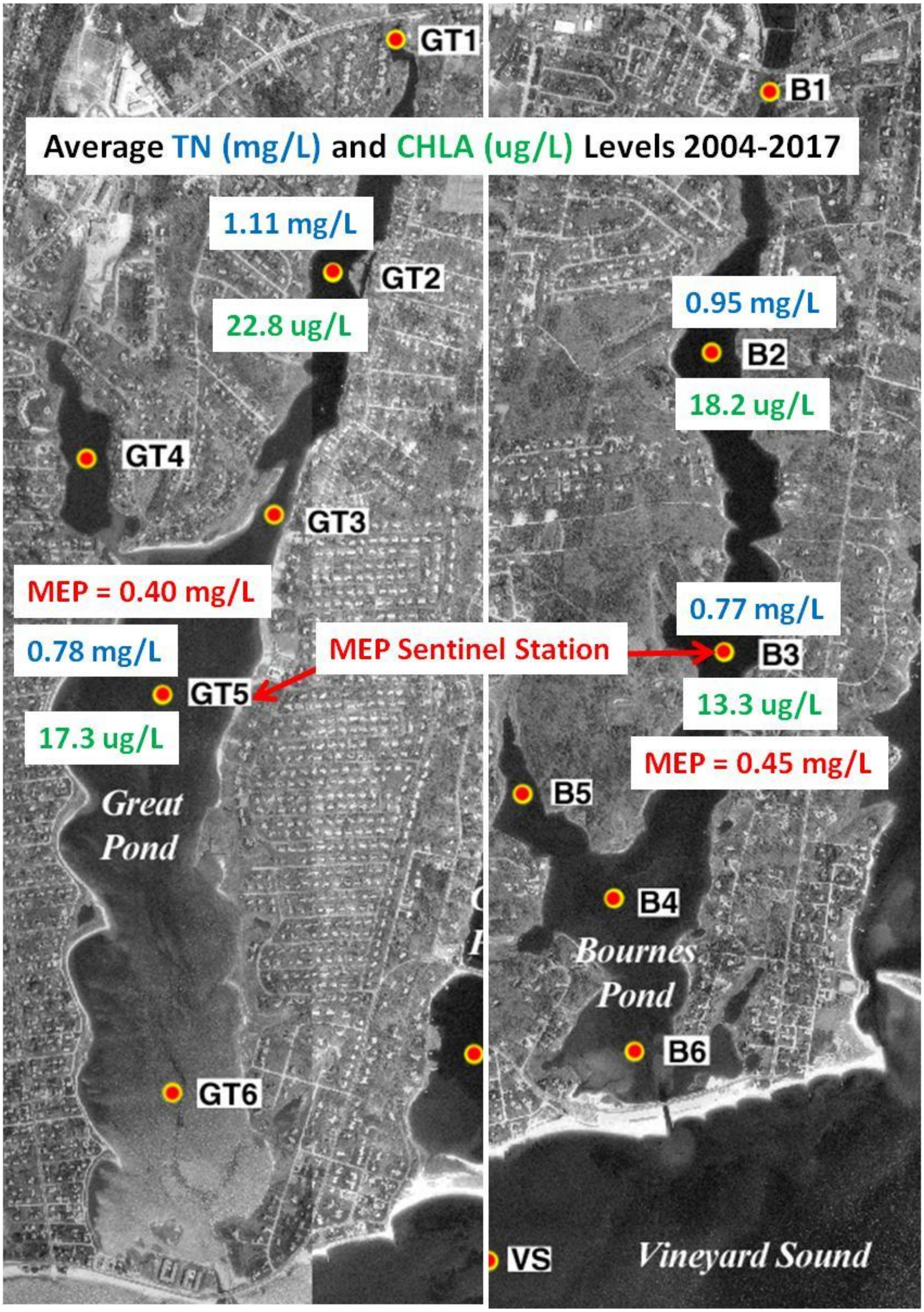
Comparison of Total Nitrogen (TN), Chlorophyll-a (CHLA) and MEP Threshold at Sentinel Station and Upper Station

A). Bournes Pond vs. Green Pond

B). Bournes Pond vs. Great Pond



A). Green Pond (left panel) vs. Bournes Pond (right panel) TN and CHLA levels.



B). Great Pond (left panel) vs. Bournes Pond (right panel) TN and CHLA levels.